PC-SIGNAL™

Basic Module

User Manual

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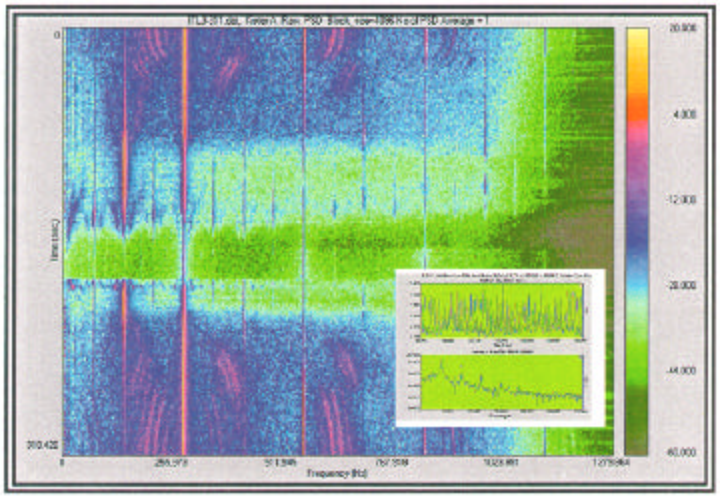
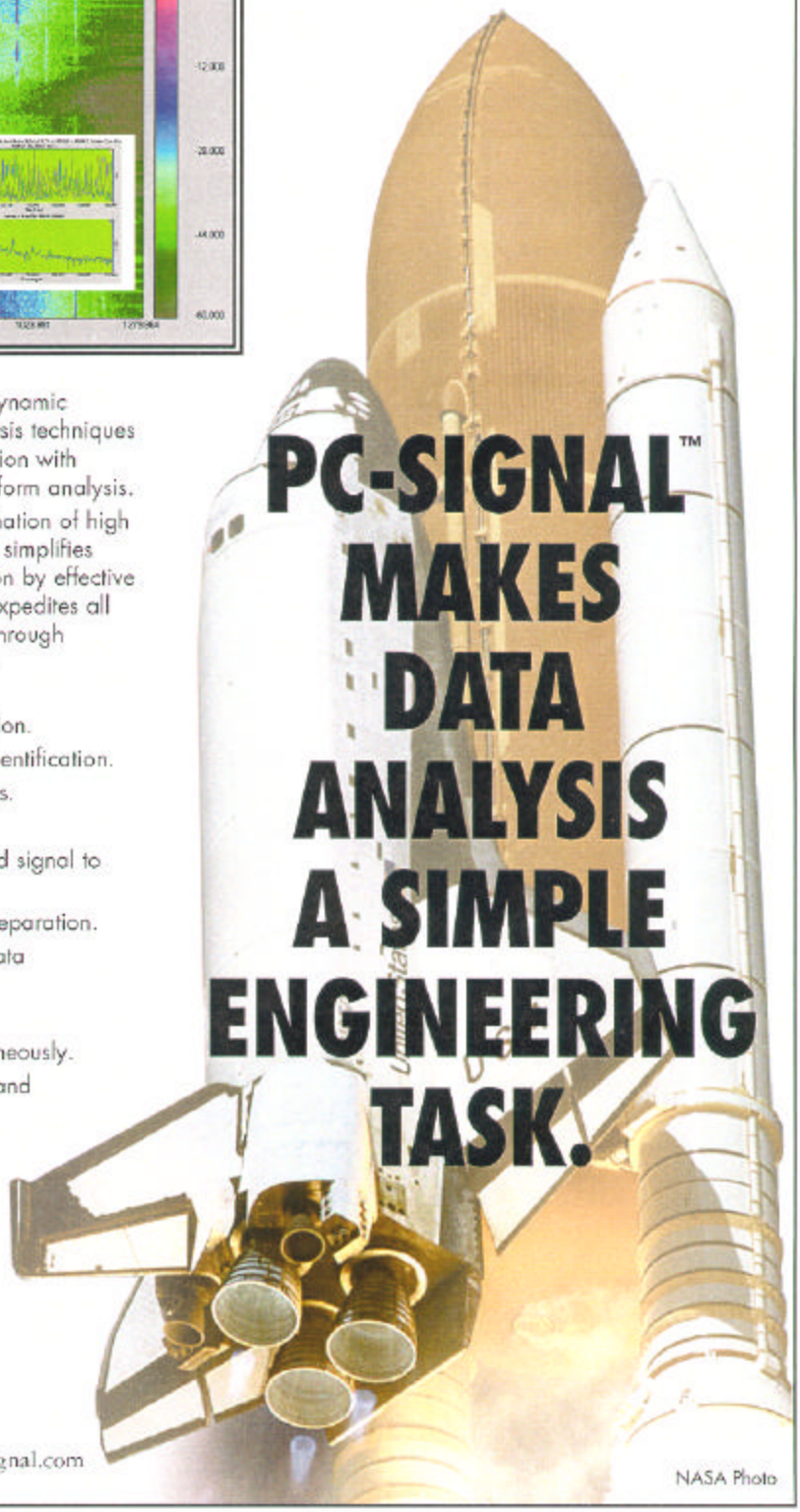


PC-SIGNAL™ software scrutinizes complex dynamic signatures and offers specialized signal analysis techniques for rotating machinery diagnostics in conjunction with comprehensive capabilities for spectral/waveform analysis.

With the same tools experts use in the examination of high speed rocket engine turbopumps, PC-SIGNAL simplifies every aspect of the signal processing operation by effective application of its graphical user interface. It expedites all steps from importing diverse raw signal files through processing and display of engineering results.

PC-SIGNAL offers:

- The latest technology for diagnostic evaluation.
- Robust signal enhancement and anomaly identification.
- User-friendly GUI control of program options.
- Powerful visualization.
- Parallel audio playback of raw or processed signal to speaker or sound card.
- Complete set of output formats for report preparation.
- Automated batch processing of extensive data analysis tasks.
- No programming required to save time.
- Display of many data formats/plots simultaneously.
- Health Monitoring Module - provides easy and flexible database creation of processed signatures, effortless recall for trend and statistical analysis.
- Simple interfacing to real time monitoring and acquisition on various PC DAQ platforms (NI,DT, etc.).



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Introduction to PC-SIGNAL™

1.1 Introduction

PC-SIGNAL™ is a PC-based dynamic signal analysis software package running under the PC Window Environment. The package makes signal processing a simple task for analyzing vibration, acoustic, strain, or other dynamic signal measurements. Other than its general capability for spectral/waveform analysis, it includes a number of specialized signal analysis techniques. The special techniques are useful for engine/machinery diagnostic evaluation, bearing/gearbox and drive train signature analysis, and vibration signature analysis. The package saves enormous amounts of time by eliminating the programming effort that used to be required to perform sophisticated signal analysis. PC-SIGNAL simplifies every aspect of the signal processing operation by effective application of its graphical user interface. It expedites all steps from importing raw signal data files through choice of processing algorithm to outputting the results. PC-SIGNAL offers:

- Latest technology for signal analysis
- User-friendly GUI control of program options
- Powerful visualization
- Audio playback to PC Speaker
- Ease of report & presentation generation - provides various output format in a standard hard copy data plot, or electronics copy in bitmap format.
- Automate large/repeated data processing tasks with batch mode
- No Programming required
- Display large number of data channel plots simultaneously - User can select the number of processed data plots to be displayed and printed simultaneously with easy selection of the colors and labels for each plots from a menu
- More than 50 analysis techniques available - User can change analysis option on the fly through the user interface and see results instantly.
- Easy selection of the processing time blocks from a Reference Window display
- Move the processing time block through the duration of the entire measurement
- Cost effective system: PC-Based

The user gets immediate visual feed back with graphical data plots in either two-dimensional or three-dimensional graphs.

PC-SIGNAL lets a user quickly locate signal components. The program provides tools to enhance the presence of components to demonstrate their presence in the data plots more prominently. Several mathematical routines and filtering processes to reduce unwanted noise and other signal contamination are built in. The package provides an array of spectral analysis procedures that help a user to make intelligent conclusions for many applications. PC-SIGNAL procedures include:

- Waveform Statistical Metrics
- Auto- and cross- Spectral Analysis with Multiple window selection to minimize data leakage

- Linear Correlation/Coherence analysis
- Transfer Function & Phase tracking
- 3D Time/Frequency Waterfall & Spectrogram
- Filtering (High-Pass, Low-Pass, Band-Pass) with easy selection of filter type and parameters graphically
- Spectral Components Tracking
- Histogram & Statistics (Mean, RMS, Skewness, Kurtosis, Max/Min, Crest Factor, etc)
- Shock Spectrum
- Unique Function Window design for displaying multiple process results for a given measurement simultaneously or multiple measurement with a selected processing method.

PC-SIGNAL provides the user with a batch processing capability where many measurements can be processed with a common sequence of algorithm processing parameters and display format. Under batch, the program processes each selected measurement and prints the result unattended.

PC-SIGNAL offers multiple user-friendly methods to manipulate data. The user can inspect the data stream simultaneously in the time domain (in any or all moment format), the spectral domain, and the cross correlation format, in either or both time and spectral based display configurations. Display smoothing options allow the choice of a large number of parameters while maintaining the integrity of the original data stream.

PC-SIGNAL provides easy visual interpretation of a user's signal analysis results. The program automatically plots peaks, contours, and surfaces to enhance the significance of results. The users can clearly present results with control over titles, fonts, colors, scaling, labels, grid and plot types. The results can be saved as bitmap files for future easy recall.

The Advanced Module includes a number of specialized diagnostic signature analysis techniques for rotary machinery diagnostics and bearing/gearbox diagnostics. These analysis tools are also useful for signal enhancement, fault detection and anomaly identification for diagnostic evaluation.

- PSEM - a phase synchronized technique for RPM-related Signal Transformation and Identification
- CPLE™ - a signal enhancement technique for RPM-related vibration signal.
- RPM Coherence - a spectral type of coherence function representing the phase correlation of any vibration components w.r.t. RPM.
- Nonlinear Bi-&Tri-spectral/coherence analysis - nonlinear correlation detection and Identification
- Envelop Analysis - high frequency envelop analysis for amplitude demodulation
- CPWBD - coherent phase demodulation technique for pump cavitation detection
- Order Tracking - order analysis
- STA/SPA - synchronized time/phase average for gearbox vibration signal analysis

A customized version of PC-SIGNAL can be built for any special requirement from the PC-SIGNAL module such as:

- Automating/integrating special analysis procedures
- Monitoring - database & trend analysis

PC-SIGNAL has been applied to:

- Space Shuttle Main Engine (SSME) post test/flight diagnosis & anomaly identification
- Weapon system vibration measurement data analysis & specification development
- Helicopter drive-train (gearbox & bearing) diagnostics
- Dynamic characterization of turbopump wind tunnel, water flow test
- Radar antenna servo drive-train health monitoring & diagnosis
- FedEx conveyor belt bearing fault detection.

1.2 Program Overview

PC-SIGNAL program execution is performed through the main menu items:

(1) **File -** To select and open a data file for processing and analysis, view/edit the header information of the opened data file, and select default printer to print output to.

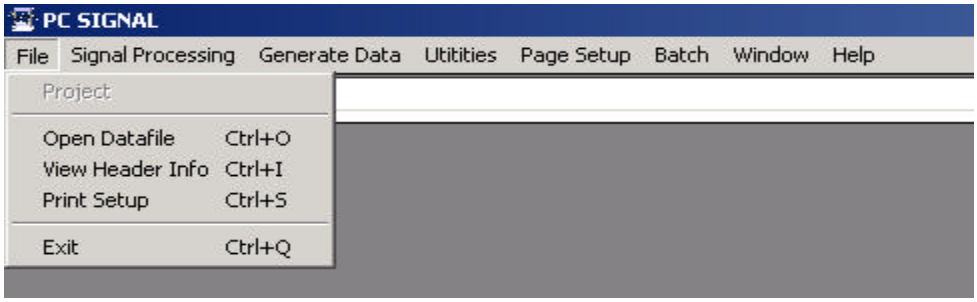


Figure 1.1 – File Menu Options

(2) **Signal Processing** – To perform signal processing of the opened data file and display the results in various function format.

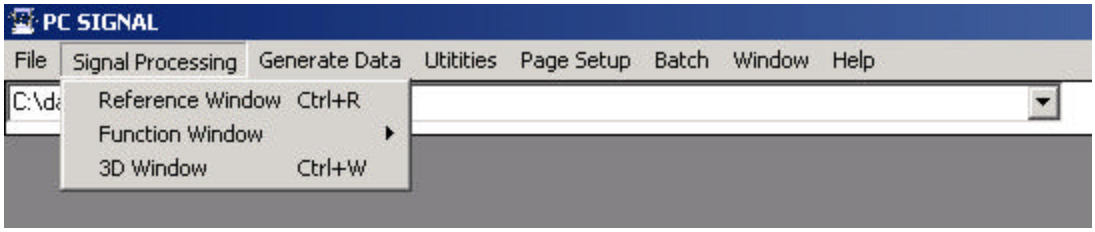


Figure 1.2 – Signal Processing Menu Options

(3) **Generate Data** - To perform various signal processing of the selected data file and store the result in an output file.

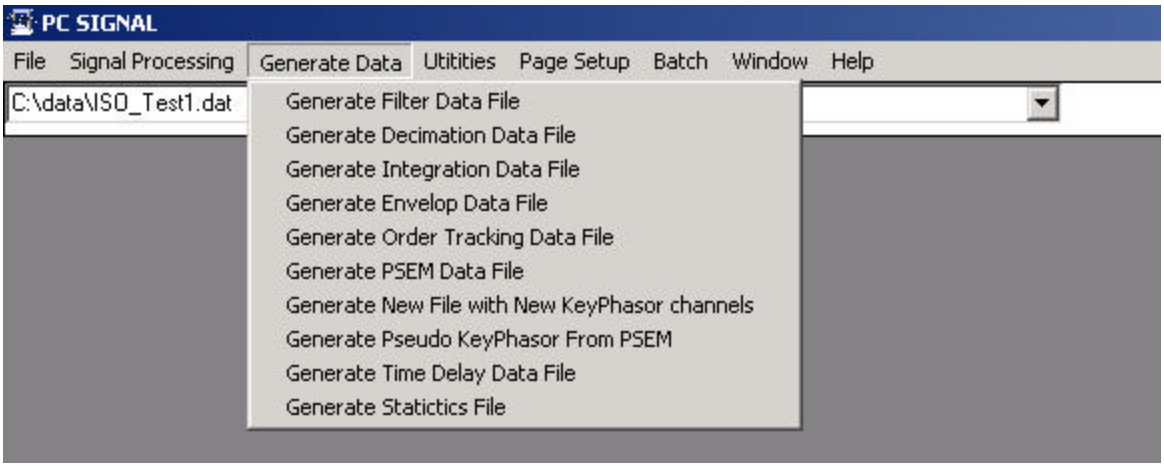


Figure 1.3 – Generate Data Menu Options

(4) **Utility** – Provide a number of utility tools to extract or merge data from ASCII or binary files, or to convert data file in other format into PC-SIGNAL format.

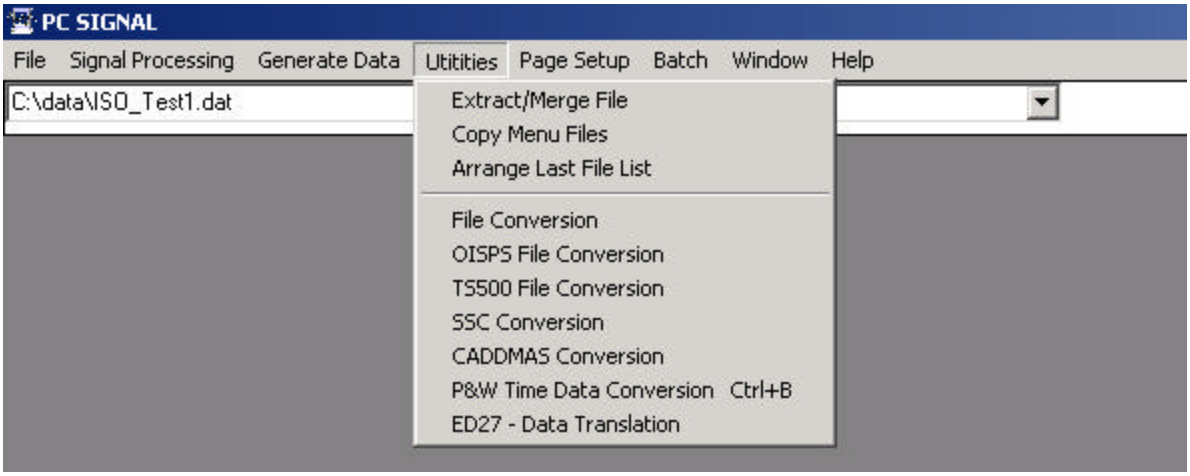


Figure 1.4 – Utilities Menu Options

(5) **Page Setup** - To configure the overall page setup (x/y scale, labels, color etc.) for all plots displayed either on screen or in print out. Also used to set line colors for the selected plot.

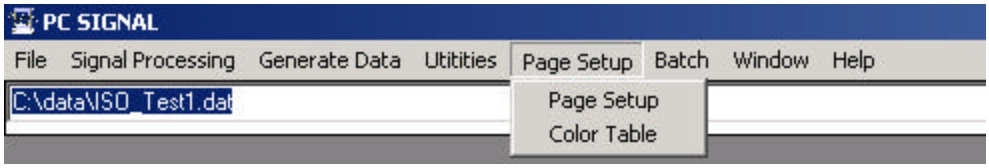


Figure 1.5 – Page Setup Menu Options

(6) **Batch** – To automate a sequence of processing tasks as a batch job.

(7) **Window –** To Rearrange multiple windows displayed on screen.

(8) **Help** – To provide on-line help

1.3 Mouse Button Operation in PC-SIGNAL

1.3.1 Left Mouse Button

In PC Signal, mouse has several uses. Whenever mouse moves over a graph, a marker appears. The crossing point of the marker can be used to determine exact coordinates of points on the graph. The coordinates are displayed on top portion of the page. If there exists more than one graph, the coordinates corresponds only to the current graph the mouse pointer is active, denoted by red color "M" on upper right hand corner.

1.3.2 Left Mouse Single Click

While the mouse pointer is on a graph, user can click once to find a peak nearest to the current mouse position. The peak found is governed by the "Peak Frequency Locking Mouse Marker Window," set in the "Processing Parameters."

1.3.3 Left Mouse Double Click

If left mouse button is double clicked when it is within a graph box, a zoom window containing that graph will appear. In the "Zoom Window," user can perform any kind of graph manipulation as if it were still in the "Function Window."

1.3.4 Left Mouse Pressed-Drag-and-Release

This implies to the case when left mouse button is pressed down, dragged and released. This action results in zooming the graph the mouse pointer is currently on. If "Sync Zoom" is on, all graphs in the "Plot Window" will be zoomed in. To return to normal view, select "Zoom Out" in "Right Mouse Click."

1.3.5 Right Mouse Button

The right mouse button, when used in the "Function Window," invokes a set of options such as printing the plots, save the plot in either ASCII or bitmap file format, perform frequency matching, etc.

2.0 File (Input File Selection, View Header Information, and Printer Selection)

"File**"** Menu item allows a user to select a data file for processing, view/edit the header information of the selected data file, and select the default printer to print outputs.

2.1 "Open DataFile" - Input Data File Selection

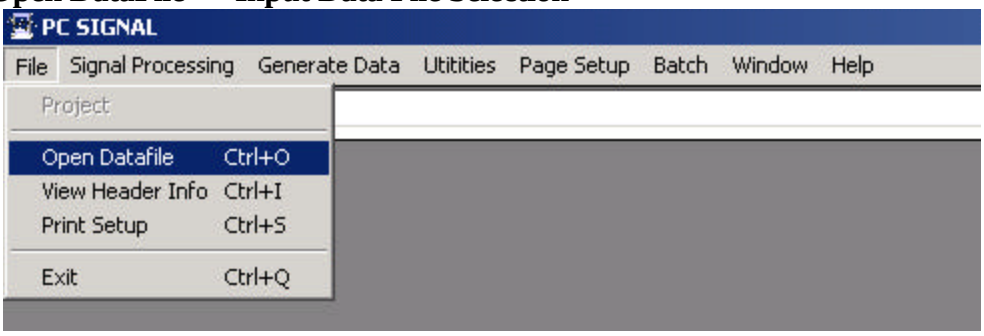


Figure 2.1 – Input Data File Selection

The first action by a user is to select the Data File to be processed. Click "File" -> "Open Datafile" to select the desired data file for processing.

Clicking on the drop-down button will display the previous selected data files. The file names are sorted in the most-recently used order. Select on one of these file names will result in opening that data file for processing.

Each data file is represented by 2 different parts (2 different files in disk):
(1) XXXX.dat - Contains data points in binary format.
(2) XXXX.menu - Contains header information (e.g. Sampling Frequency, Time, number of channel, Channel Information, etc.)

2.2 View Header Information

Once a data file is selected, the user can view the data file's header information by selecting "File" -> "View Header Info." Figure 2.2 shows an example of the "Channel Information" sub-window that pops up after the selection.

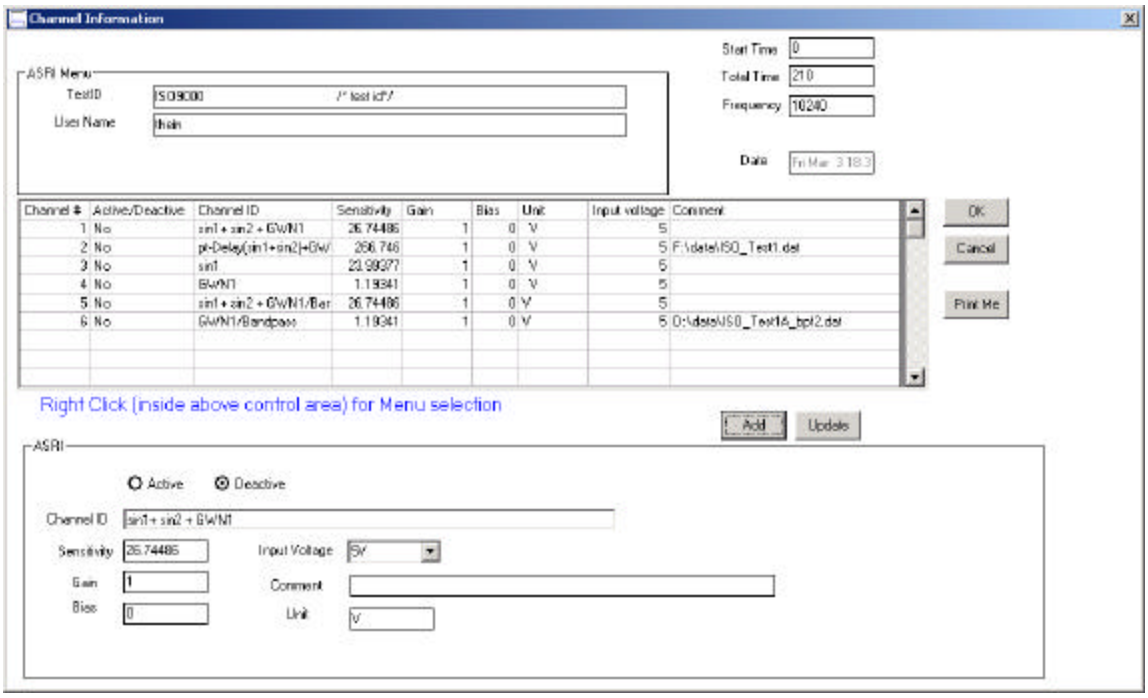


Figure 2.2. Channel Information Window

User can change the header information by directly typing in each entry box. To change the information in the channel information box, first select the desired channel by clicking on the line that channel. The user can then make any changes by typing in the channel information box. Click "Update" to confirm changes for each channel. After entering new channel information and clicking "Add" will add a new channel into current header file.

To save the updated information back into the file, click "OK," and a file selection sub-window as shown in figure 2.3 will pop. Click "Save" to save the header file. User can also specify a different header file name.

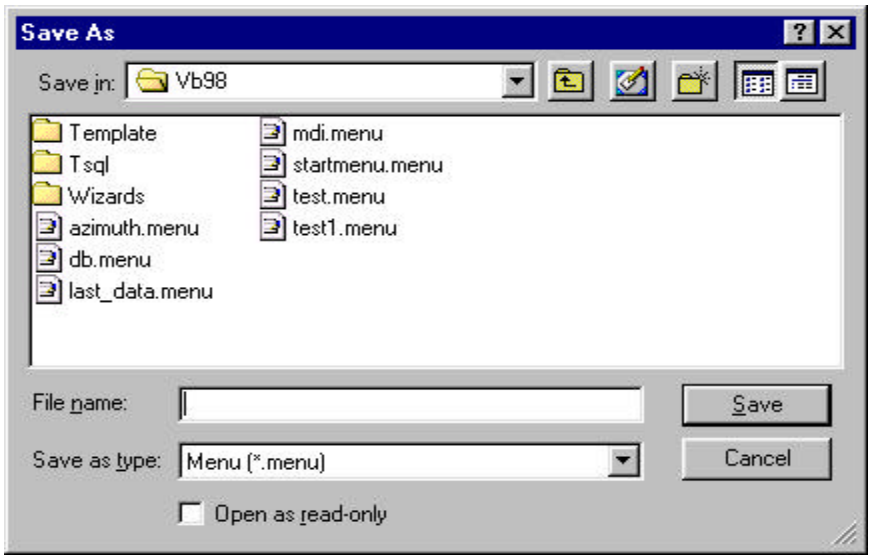


Figure 2.3 - Save Header File

2.3 Print Setup – Selecting Default Printer

This option allows a user to select or set the default printer, set the number of copies to be printed. Other options, such as "Page Range," or "Layout" are set automatically by PC Signal and will not have an effect on the printed copies.

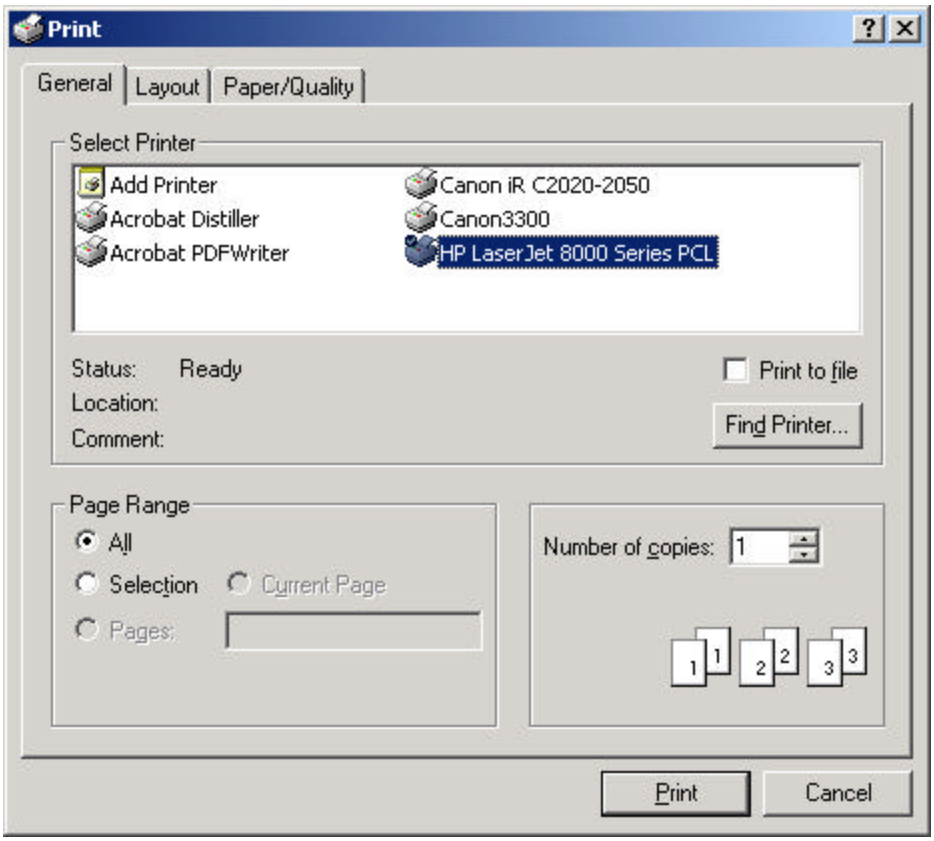


Figure 2.4 – Print Setup

3.0 Signal Processing – Reference Window

"Signal Processing" allows a user to perform various signal processing of the selected data file and display the results in a number of function format. Signal processing can be performed in the following 3 different Windows:

(1) Reference Window - This option provides a *time reference* of the overall data file by displaying its reduced (or compressed) waveform or statistics so that the user can conveniently locate and select any desired time segment for detailed analysis in the "Function Window."

(2) Function Window - This processing window enables a user to process data using any of the available processing functions and display the processing result in 2D X-Y format within multiple sub-windows. Most of the signal processing of PC-SIGNAL is performed in this option.

(3) 3D Plot Window - This window allows the user to display 3D Spectrogram, Waterfall, Topo, or 3D Bi-Coherence graphs.

3.1 Reduction Sliding Window in Reference Window

This Reference Window provides a *time reference* of the data file by displaying an overall picture of the entire test profile/characteristic in the form of reduced statistics so that the user can conveniently locate and select any desired time segment for detailed analysis in the "Function Window." In this "Reference Window," raw data waveform is reduced into a readily comprehensible plot as a function of time in the form of reduced statistics (Mean, RMS, Skewness, Kurtosis), or compressed waveform (Max/Min) or RPM (if a key-phasor measurement is available) for the selected channels. Such waveform reduction is performed through a sliding "Reduction Sliding Window" as depicted in figure 3-1. Within each sliding Reduction Sliding Window, a single reduction value (two for Max/Min reduction) will be generated and plotted. As a result, an overall reduced waveform or statistics will be displayed in the "Reference Window" plot. This option provides a convenient mean to select time for further processing in the "Function Window" by dragging mouse over the reduced waveform.

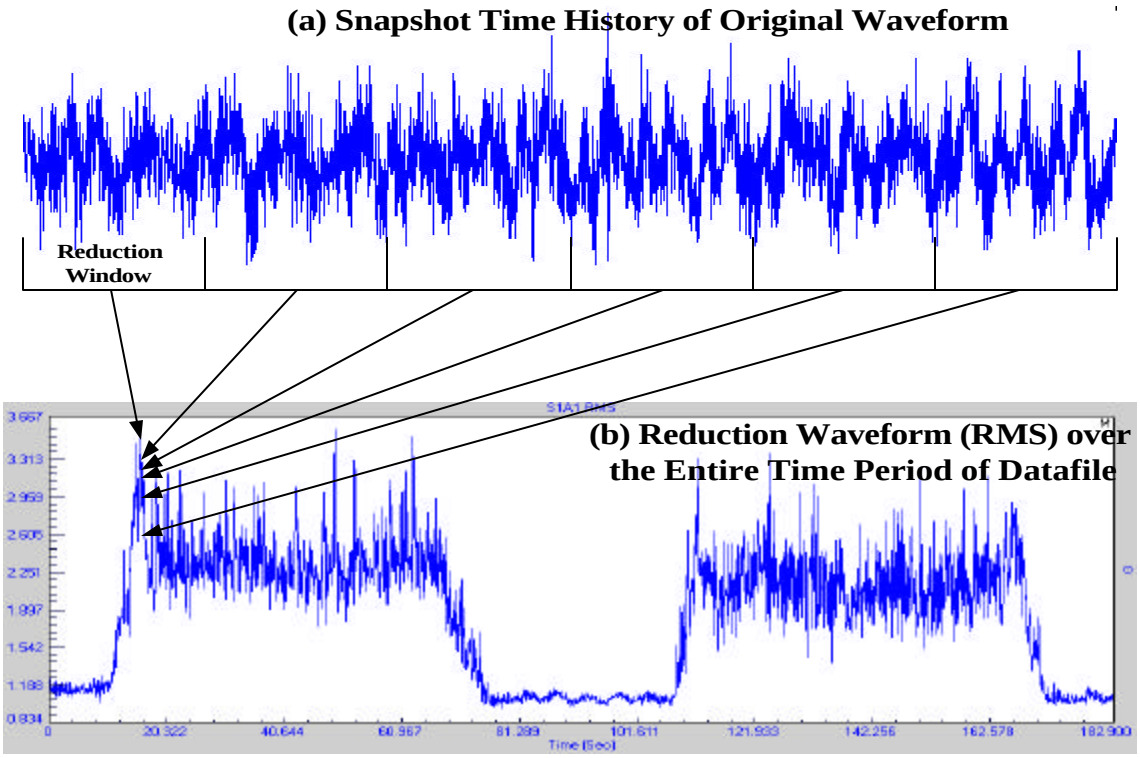

(a) Snapshot Time History of Original Waveform
Reduction Window
(b) Reduction Waveform (RMS) over the Entire Time Period of Datafile
Time (Sec)

Figure 3.1 - (a) Reduction Sliding Window; (b) RMS Reduction Waveform

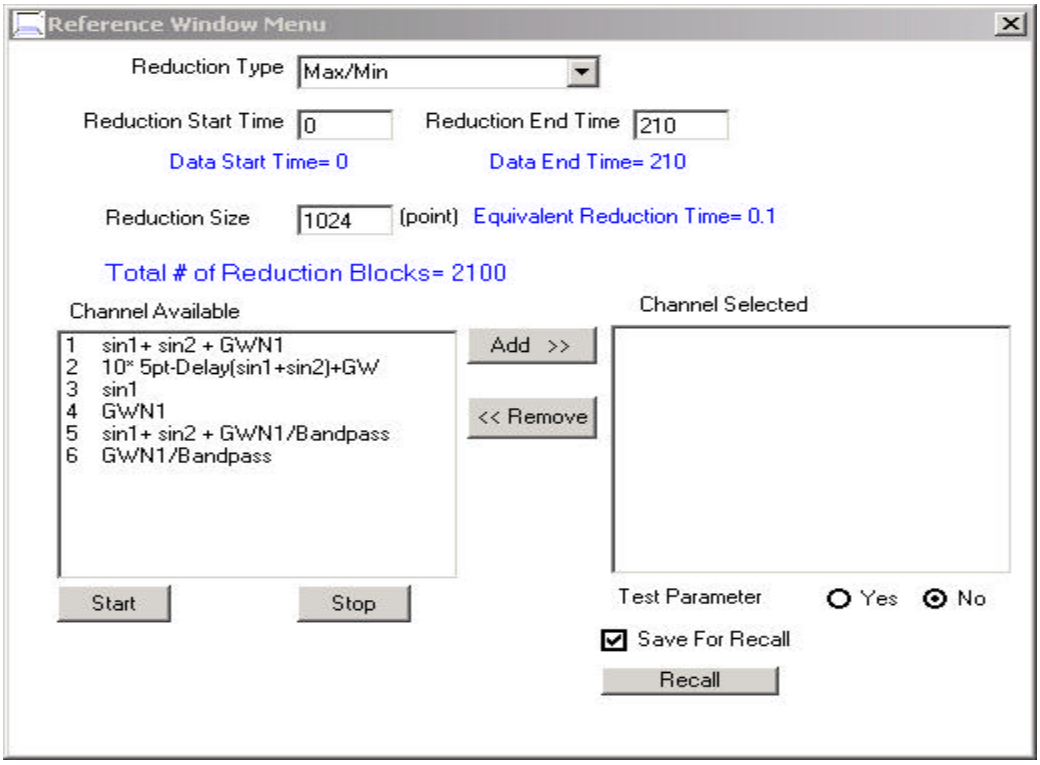


Figure 3.2 - Menu Page for Reference Window

3.2 Reference Window Menu

Figure 3.2 shows the menu page for the "Reference Window." It allows a user to choose the reduction type (Mean, RMS, Skewness, Kurtosis, etc.), reduction start/end time, reduction size and measurement(s) to be processed. Explanations for each menu item are as follows:

Table3-1 : Menu Items of Reference Window's Menu Page

Menu Item Name	Menu Item Description
Reduction type	Defines reduction type to be applied to the raw data. Six choices available are available: Mean, RMS, Max/Min, Skewness, Kurtosis, and Crest Factor. Can choose RPM profile option if the key-phasor measurement is available.
Reduction Start Time	This is the start time for data reduction within the Reference Window (default is the start time of data file).
Reduction End Time	This is the end time for data reduction within the Reference Window (default is the end time of data file)..
Reduction Size	Reduction sliding window, in terms of number of data points, in setting plot density.
Channel Available	Name of each measurement channel available in the data file
Channel Selected	This display box shows the measurement channel(s) that have been selected for processing.

The user can select a channel for reduction by highlighting the channel name in the "Channel Available" list and clicking "Add." Highlighting and then clicking "Remove" will deselect the channels. The "Start" button, when clicked, will commence the data reduction. As a result, a "Reference Window" plot will appear that contains graphs of reduced data of selected the selected channels. The "RPM Tracking" window of the speed channel will also appear if selected. Clicking "Stop" will stop the processing.

3.3 RPM Tracking in Reference Window

This RPM Tracking option in the Reference Window provides the user a way to display an overview RPM profile of the speed (key-phasor) channel in a data file. Figure 3-3 shows the "Reference Window" menu page when the "RPM Tracking" option is selected.

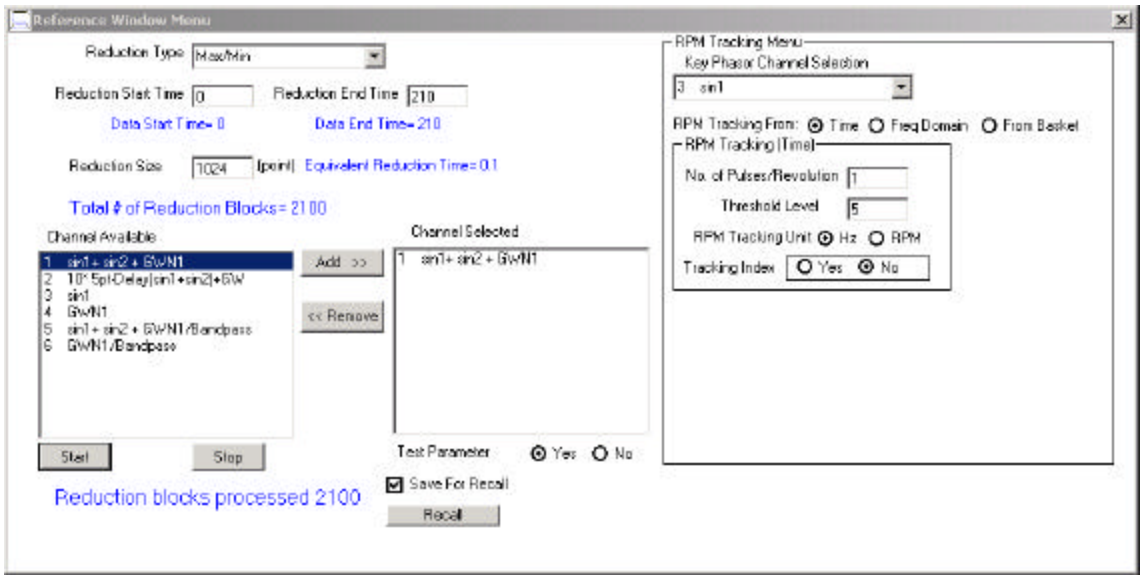


Figure 3-3: Reference Window Menu Page with RPM Tracking Menu

Menu Item	RPM Tracking Menu Item Description
No. Of pulses per Revolution	Number of pulses per revolution of the shaft that was recorded in the key-phasor measurement
Threshold Level	Threshold level applied to the key-phasor pulses for RPM counting.
Key Phasor Channel	Select the key-phasor channel

To enable this function, first click on the "Yes" button. Then specifies the number of pulses that was recorded per revolution of the shaft by entering this number in the "No. of Pulses/Revolution" box. To obtain expedient and reliable RPM Tracking, the user is advised to apply an appropriate "Threshold Level" to the speed signal waveform. This eliminates anomalous low amplitude waveform blips that the program will erroneously process as valid pulses. With RPM-Tracking option selected, PC-SIGNAL will automatically process this channel along with the other selected channels. At the conclusion of the data processing, PC-SIGNAL adds the plot to the bottom of the data window display. CAUTION: The RPM-Tracking plot will not appear if the tracking fails due to an inappropriate "Threshold Level" value. If this occurs, view the time history waveform of the key-phasor channel in the "Function Window," and then enter another "Threshold Level" value and repeat the processing.

3.4 Processing Example In Reference Window

Setup the RPM Tracking parameters as shown in Figure 3.3. Data file used is "ISO_Test1.dat." Click "Start" to begin processing. Figure 3.4 shows the resulting Max/Min Reduction along with the RPM profile.

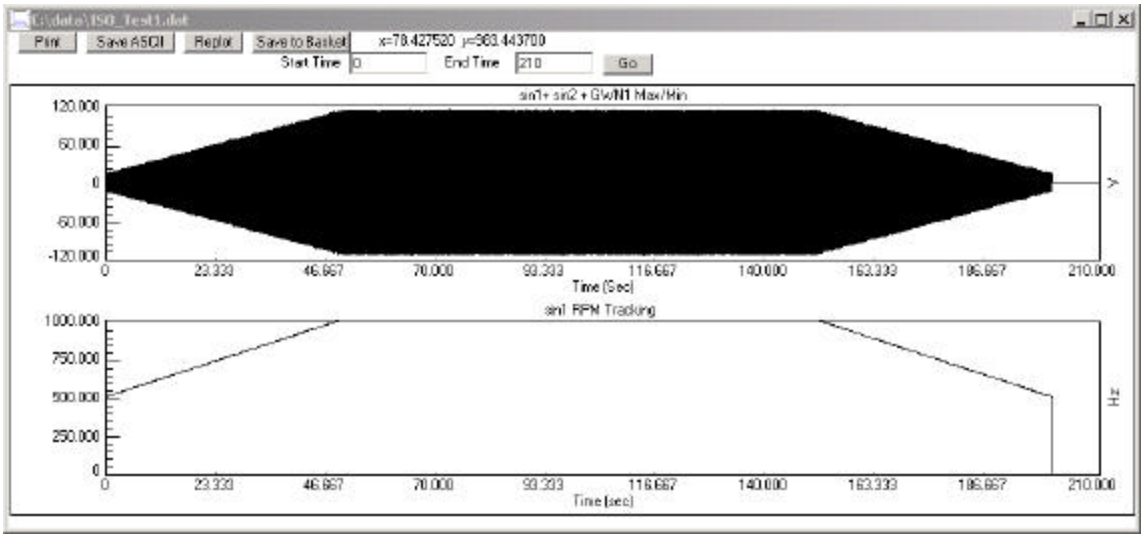


Figure 3.4 - Example of Reference Window Display

4.0 Signal Processing – Function Window

Function Window enables a user to process data using any of the available processing algorithms/functions and displays the result in 2D X-Y Format over multiple sub-windows. Most of the processing and analysis capabilities of PC-SIGNAL are performed in this Function Window. The software is very flexible because it is programmed to allow a user to process a measurement with one or more functions simultaneously, or the user can process two or more measurements simultaneously using one or more functions for each selected measurement.

4.1 "Signal/ Function" Menu group - Selection of Signal Processing & Display Format in Function Window

Figure 4.1 shows the selection of signal processing along with its display function formats in the "Function Window." All signal processing in Function Window is based on the signal flow diagram in figure 4-1(a) with its corresponding menu selection in the "Signal/Function" Menu group in figure 4-1(b). This "Signal/Function" menu group defines the signal flow and its output display format for each sub-plot. Table 4-1 lists the description of the menu items in the "Signal/Filter/Function/Channel" Menu group

Menu Item	Description of "Signal/ Function" Menu group
Signal	To select the type of signal processing on of the input raw signal x(t), ("Raw" indicates no processing). Select by using drop-down box (Figure 4-1c). Click "menu", whenever it appears, to set the parameters of signal menu; menu number used appears to the left.
Filter	To select the filtering and its parameters on the post-processed signal y(t), if 'Yes' is chosen. By click "menu" (Figure 4-1d), the filter type (bandpass, lowpass, highpass) and parameters (filter order and cutoff frequencies, etc.) along with its menu number can be selected.
Factor	To apply a scaling factor(multiplier) to the post-filtered signal z(t).
Function	To select the type of signal function (Figure 4-1e), to be generated from the post-amplified signal w(t). The output function *fx*(.) will be displayed in x/y plot format. The x-axis can be time (e.g. time history, reduction, tracking etc.), time lag (correlation function), frequency (PSD, Transfer function, coherence, shock spectra, etc.), or other parameter such as bi-frequency for bi-coherence function.. Function parameters can be set, whenever necessary, by clicking "menu" button, appeared to the right of menu number being used.
Channel	To specify the input channel x(t) to be processed.
Line Thickness	To specify the thickness of plotting line for function display
Color	To specify the color of plotting line for function display(Figure 4-1f)

Table 4.1 - Description of "Signal/ Function" Menu group in Function Window

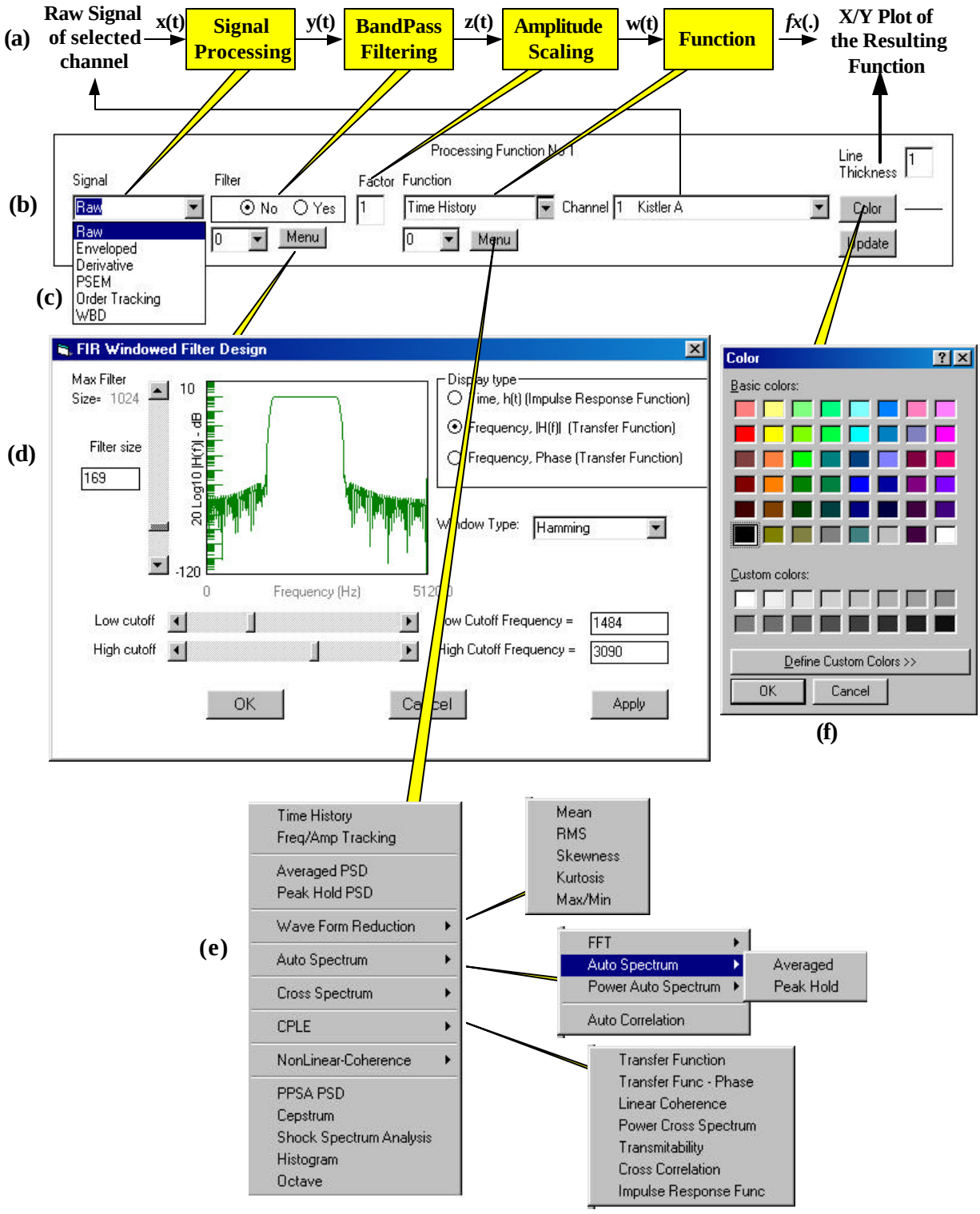


Figure 4.1 - Selection of Signal Processing & Function Display in Function Window

(a) Signal Flow Diagram
(b) Corresponding "Signal/ Function" Menu group
(c) Pull-down menu for Signal Selection
(d) Pull-down Menu for Filter Selection
(e) Pull-down Menu for Function Selection
(f) Line Color Selection

4.2 Processing Example in the Function Window

In PC Signal, almost all of signal processing are performed in Function Window. To open Function Window, select "Signal Processing" -> "Function Window" -> "Default/Custom/…" Default results in same setting as the previous window setup, and custom allows the user to specify number of rows and columns. There are also several predefined settings that a user can choose from. A sample Function Window is shown in figure 4.2.

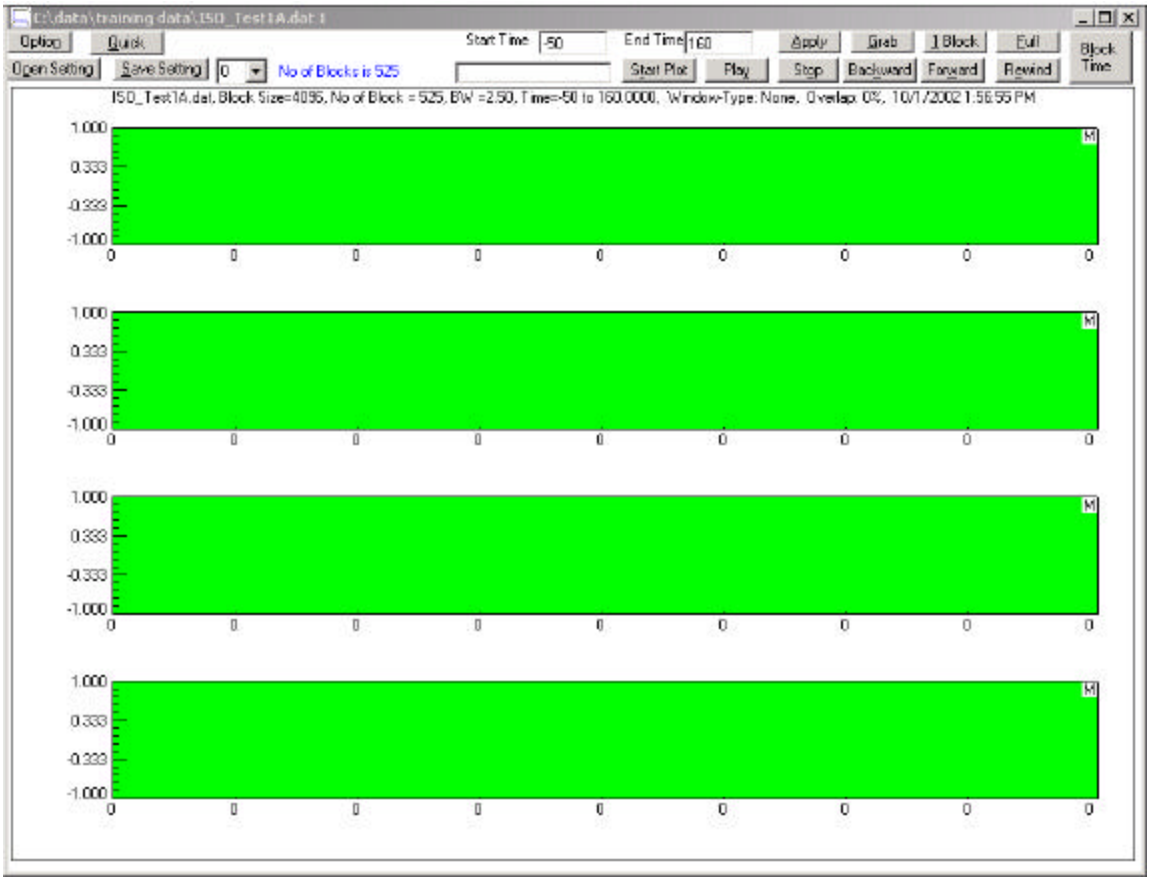


Figure 4.2 - Sample Function Window with 4 Rows and 1 Column

In PC Signal, data processing is performed in the order: "Signal" -> "Filter" -> "Function." When setting data for processing, the user will have to select "Signal" first. Only "Raw" signal processing is available in the Basic Module. Next set the Filter parameters by selecting "Yes" or "No" under "Filter." Click "Menu" to set the filter parameters. Next select the desired function.

In PC Signal, one can set processing functions several way. One of them is via the "Quick" button in the Function Window. "Quick" menu allows a user to apply the same processing function to different channels. When clicked, "Quick Menu" window appears. Set parameters as shown in figure 4.3. Click "OK" when done. Next enter "100" in "Start Time" box, click "1 Block." Click "Start Plot" to begin processing and plotting. Resulting plot is shown in figure 4.4.

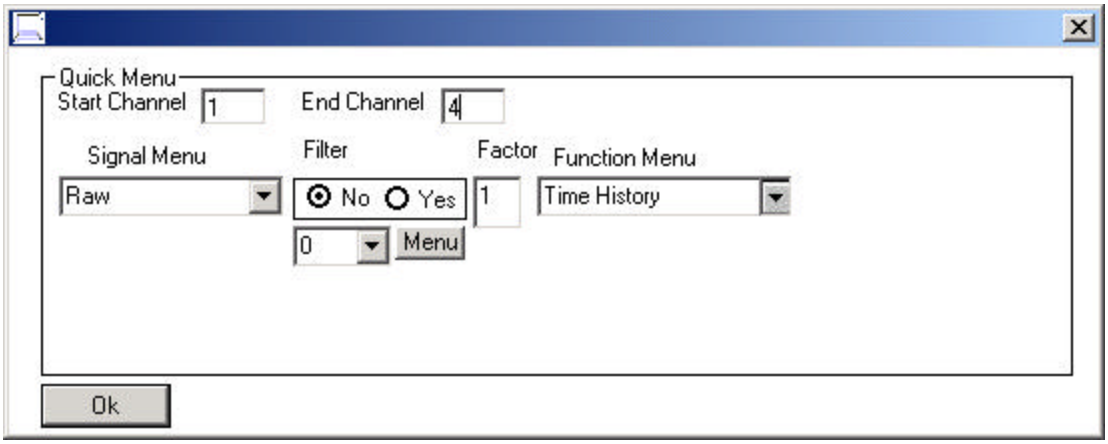


Figure 4.3 - Quick Menu with Sample Settings for Time History Plot

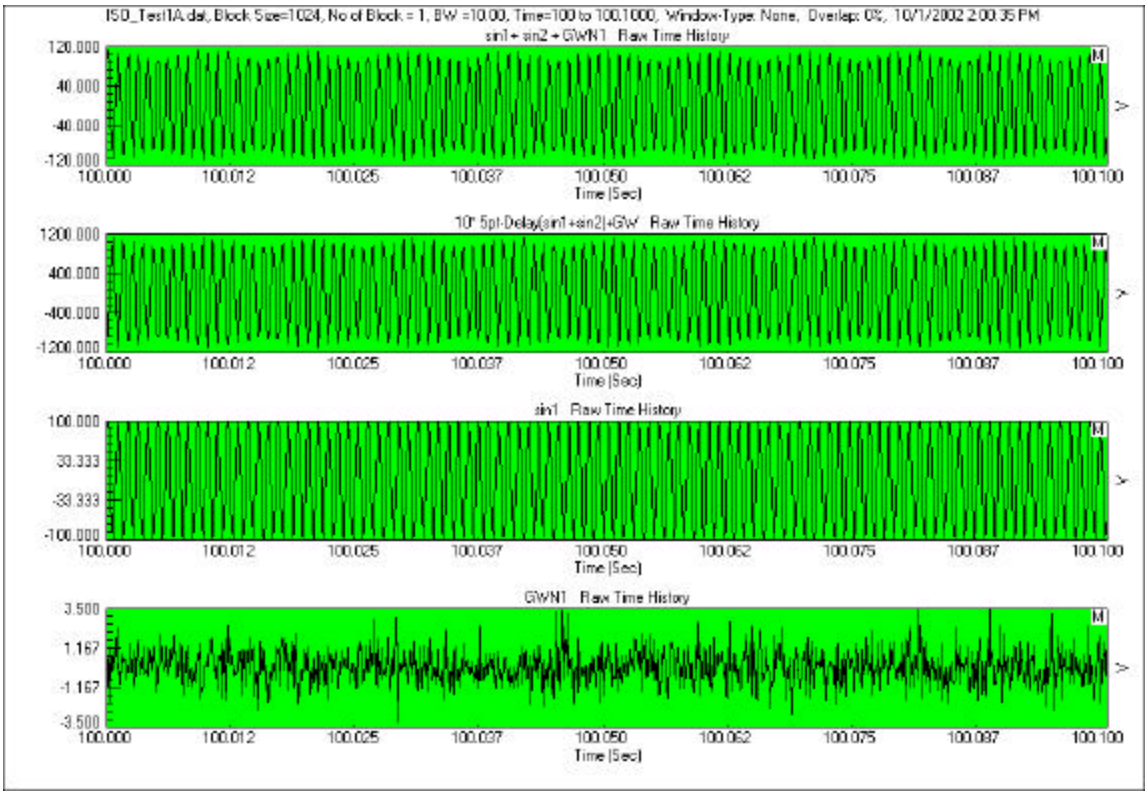


Figure 4.4 - Time History Plot

Note: To set "Block Size," click "Options" button in the "Function Window" and set/change "FFT/Data Block Size." Figure 4.5 shows the "Processing Parameters" window. "Processing Parameters" window can also be invoked by clicking right-mouse button and selecting "Processing Parameters" option.

"Start Time" and "End Time" can be entered manually. In this case "Apply" button has to be pressed to confirm.

In Function Window, you can zoom into any time or frequency range by press-drag-and-release left mouse button. Figure 4.6 shows a sample in zooming in to particular time range.

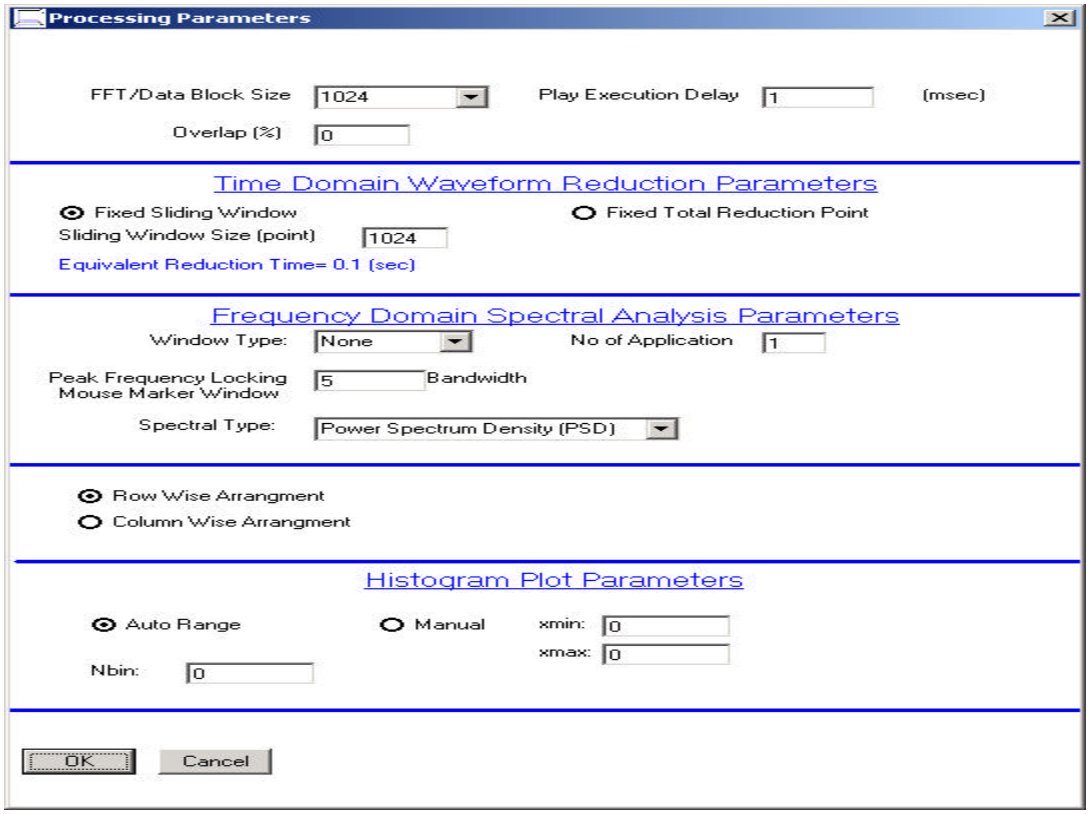


Figure 4.5 - Processing Parameters Menu

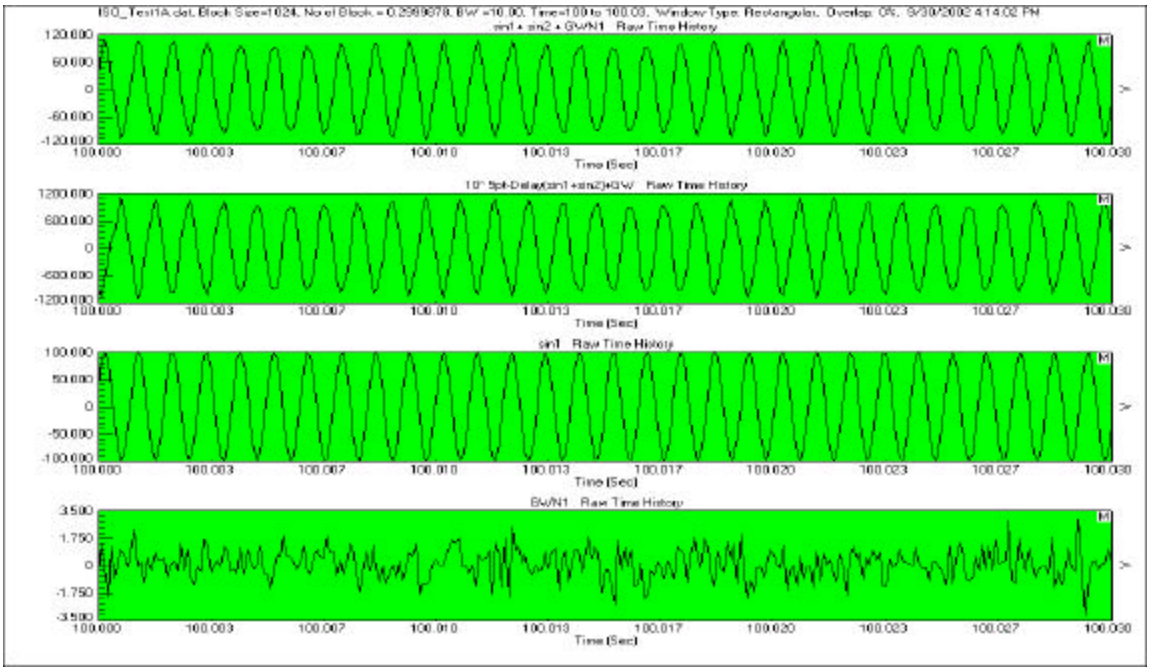


Figure 4.6 - Time History Plot when Zoomed In

Another way to set processing is via "Processing Menu." It can be called up by clicking on the "M" on top right corner of a plot. Figure 4.7 shows the "Processing Menu." Setting functions to process is similar to that of "Quick Menu." For this example, the Function Window with four rows and two columns is used. Figure 4.8 shows the

resulting plot of "Wave Form Reduction" functions. One will have to click on "M" for each function. This way, multiple functions can be plot on same window.

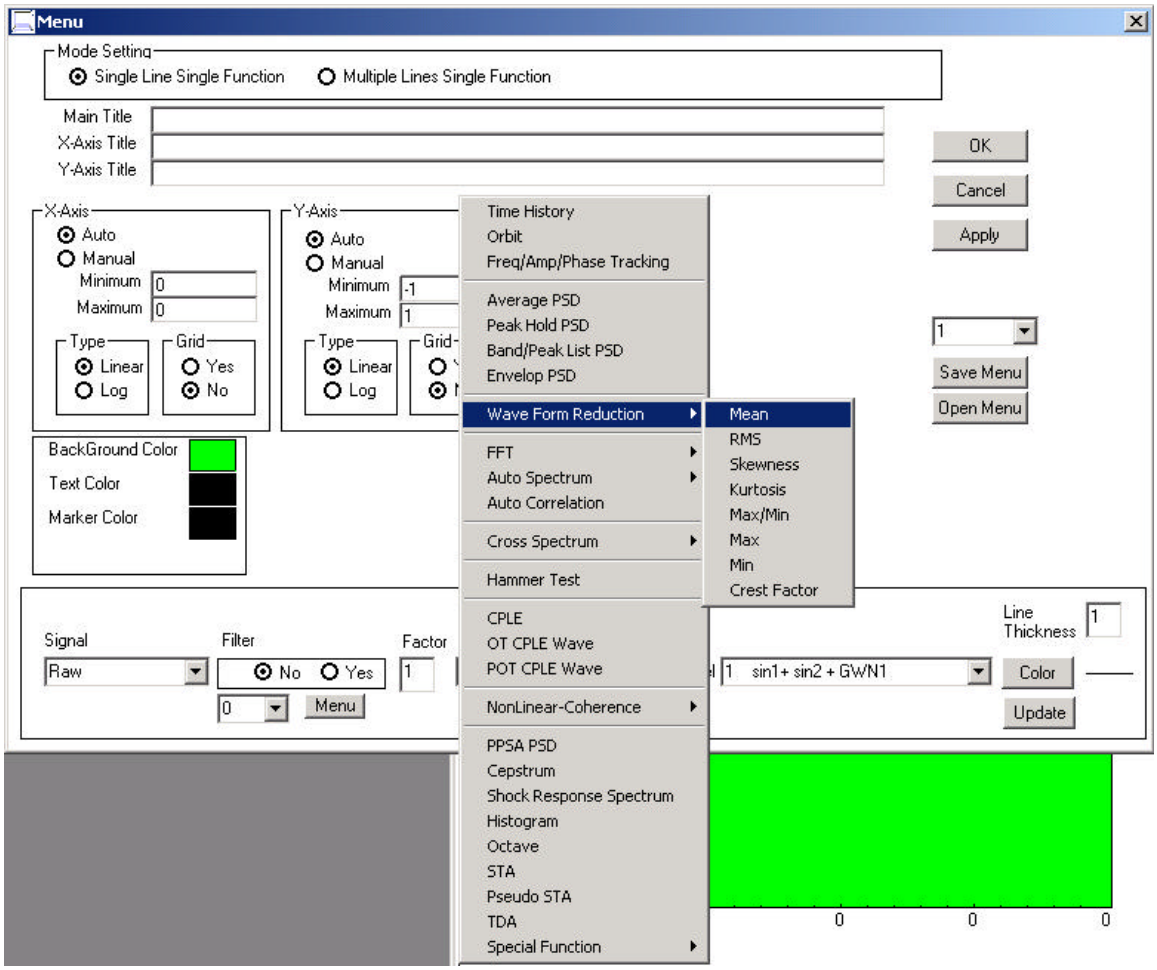


Figure 4.7 - Processing Menu with Wave Form Reduction Function Selection

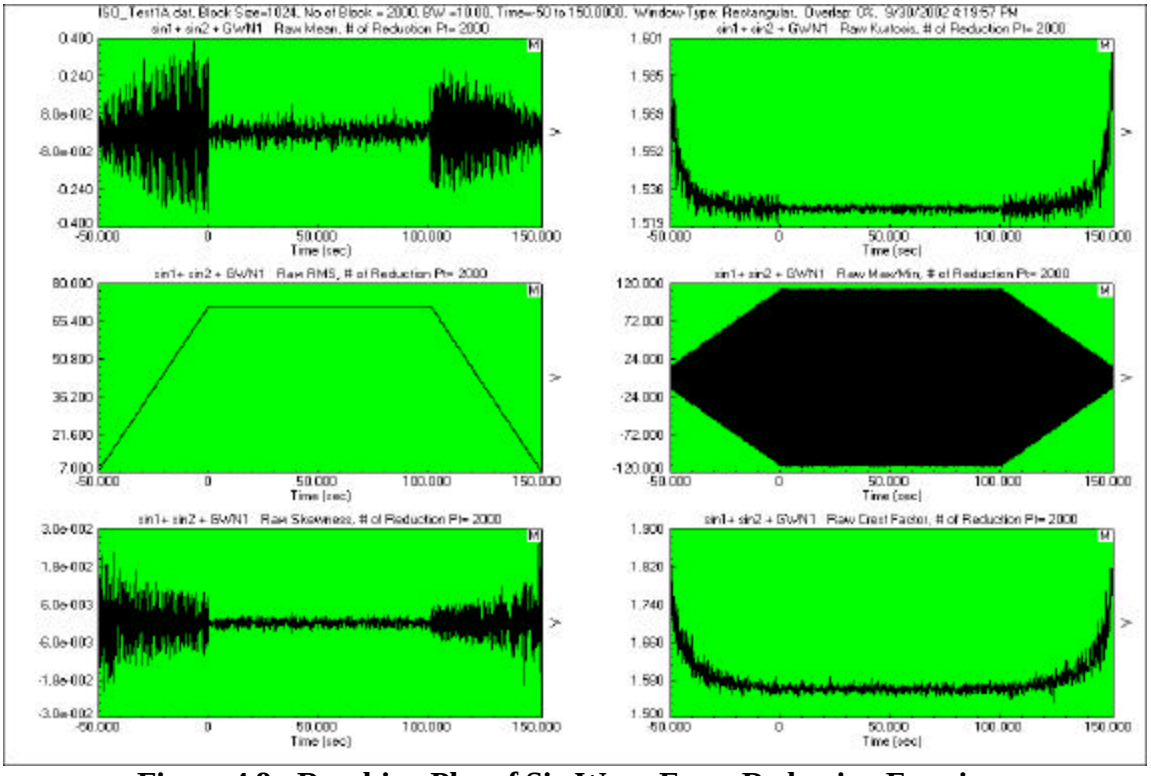

ISO_Test1A.dat, Block Size=1024, No of Block = 2000, BW =1000, Time=50 to 150.0000, Window Type: Rectangular, Overlap: 0%, 9/30/2002 4:19:57 PM
sin1 + sin2 + GWN1 Raw Mean, # of Reduction Pt= 2000
sin1 + sin2 + GWN1 Raw Kurtosis, # of Reduction Pt= 2000
sin1 + sin2 + GWN1 Raw RMS, # of Reduction Pt= 2000
sin1 + sin2 + GWN1 Raw Max/Min, # of Reduction Pt= 2000
sin1 + sin2 + GWN1 Raw Skewness, # of Reduction Pt= 2000
sin1 + sin2 + GWN1 Raw Crest Factor, # of Reduction Pt= 2000
Time (sec)

Figure 4.8 - Resulting Plot of Six Wave Form Reduction Functions

Function Window (Histogram)

For this purpose, change the row and column setup to "2x1" and "Start Time" and "End Time" to "0" and "50" respectively. From "Quick" menu in Function Window, select "Histogram" as the processing function. Click "Menu" button to set "Histogram" parameters. Figure 4.9 shows a sample setting and figure 4.10 shows the resulting plot.

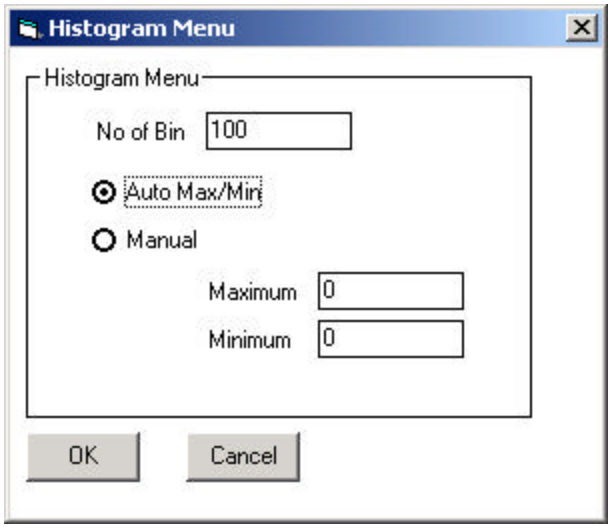


Figure 4.9 - Sample Histogram Setting

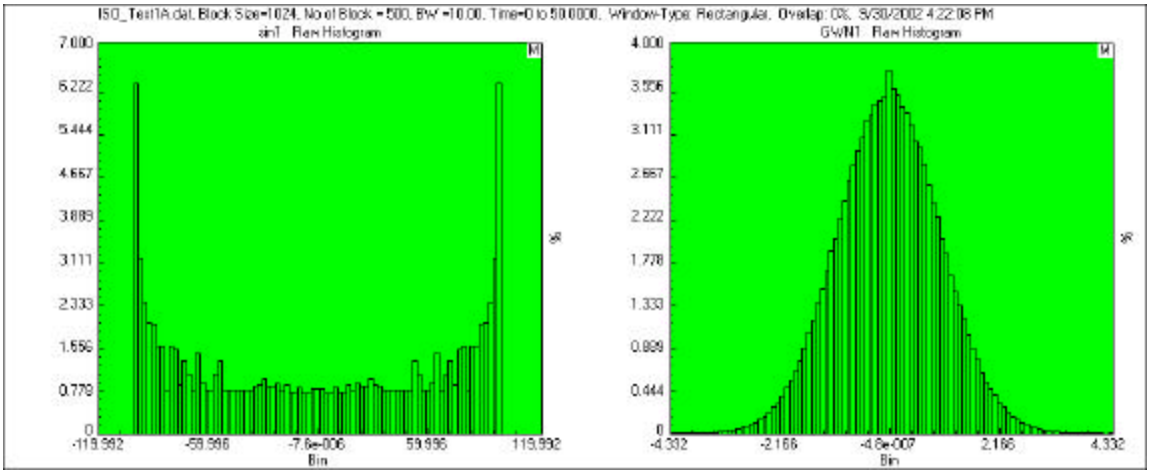

ISO_Test1A.dat, Block Size=1024, No of Block = 500, BW =10.00, Time=0 to 50.0000, Window=Type: Rectangular, Overlap: 0%, 9/30/2002 4:22:08 PM
sin1 Raw Histogram
GWN1 Raw Histogram
Bin
%

Figure 4.10 - Resulting Histogram Plot

Function Window (PSD)

Using "2x2" setup, and "FFT/Block Size" of 4096, figure 4.11 shows the setup and figures 4.12 (1 block) and 13&14 (multiple blocks average) resulting plots.

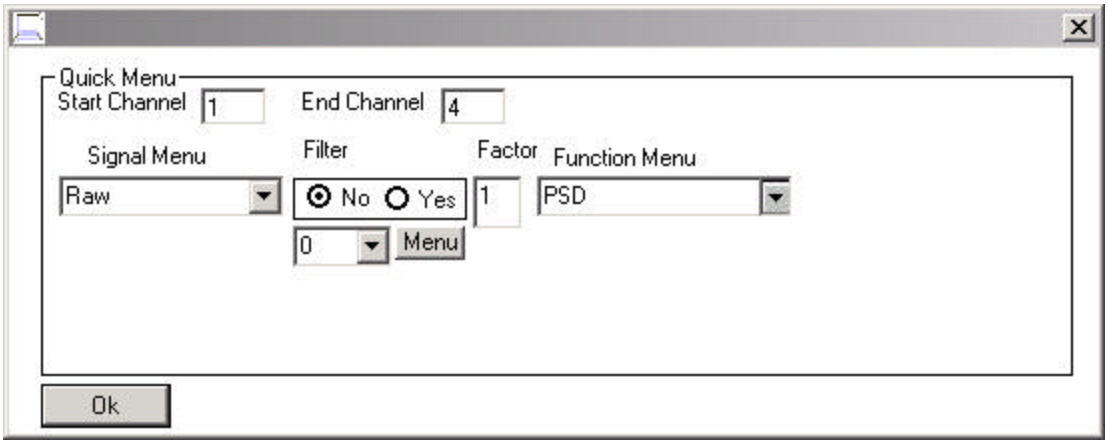


Figure 4.11 - Setup to Perform Four PSD Plots

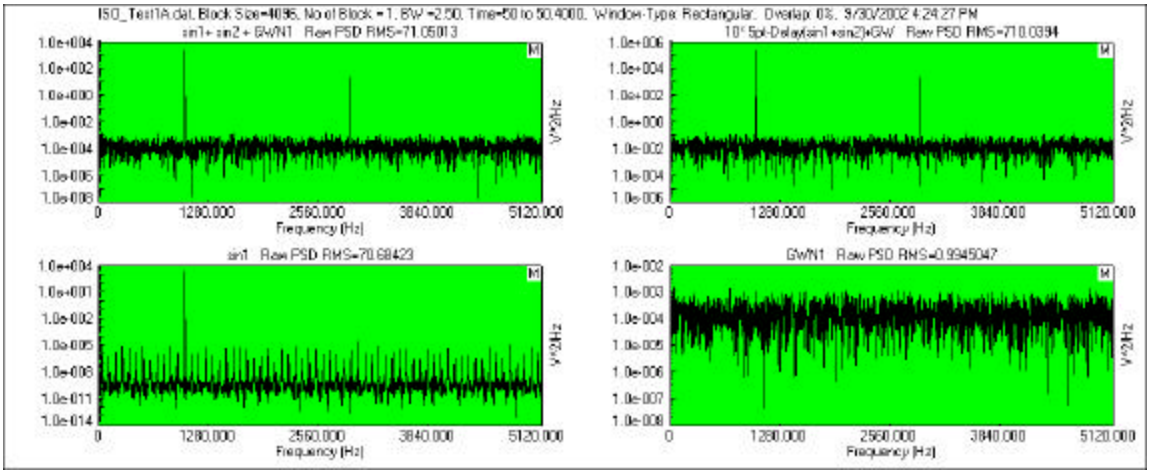

ISO_Test1A.dat, Block Size=4096, No of Block = 1, BW =2.50, Time=50 to 50.4000, Window=Type: Rectangular, Overlap: 0%, 9/30/2002 4:24:27 PM
sin1+ sin2 + GWN1 Raw PSD RMS=71.05013
10^5pt-Delay(sin1+sin2)+GW Raw PSD RMS=710.0394
sin1 Raw PSD RMS=70.68423
GWN1 Raw PSD RMS=0.9945047
Frequency (Hz)
V^2/Hz

Figure 4.12 - Resulting PSD Plot (1 Block) T=50 to 50.4 sec

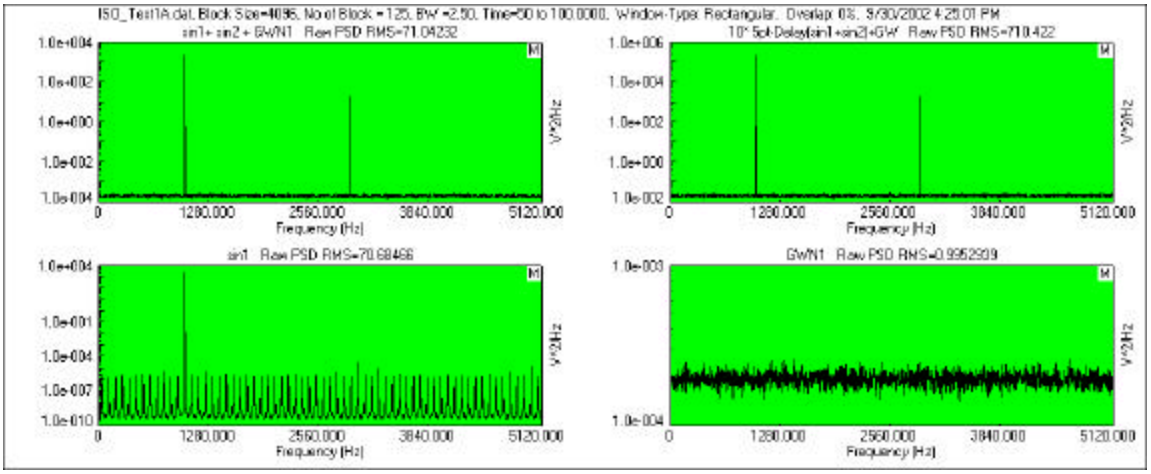


Figure 4.13 - Resulting PSD Plot (50 Blocks) T=50 to 100 sec

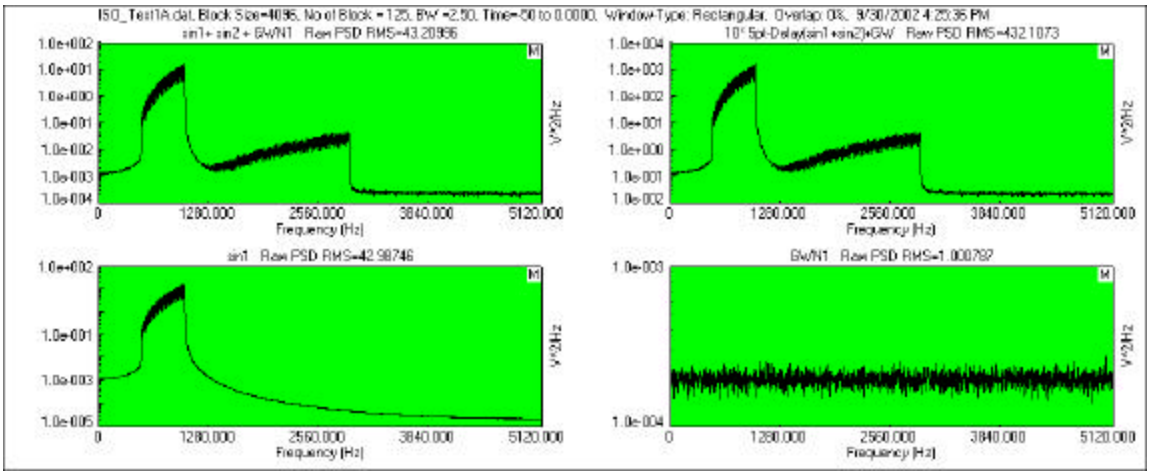


Figure 4.14 - Resulting PSD Plot (50 Blocks) T=-50 to 0 sec

Following two figures shows the setup and resulting filtered PSD plot. To setup "Filter" parameters, click on "Menu."

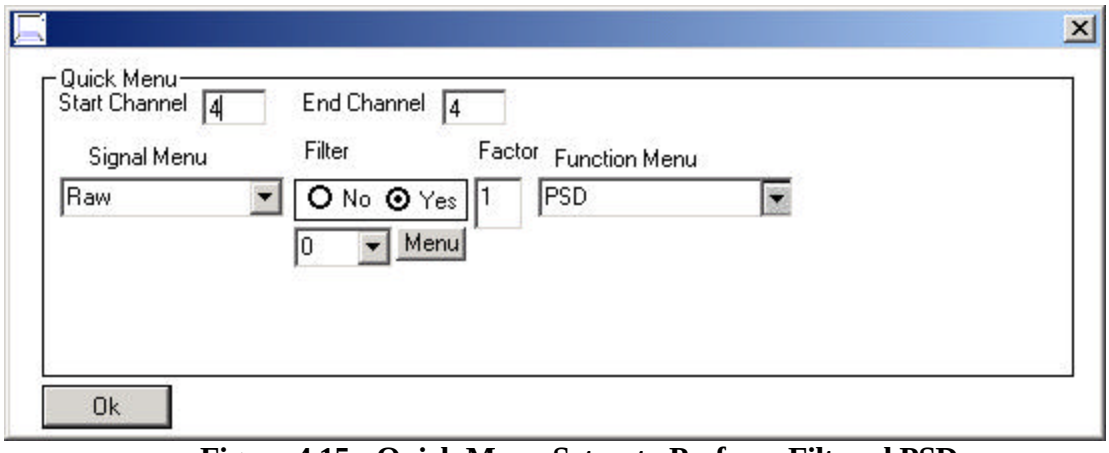


Figure 4.15 - Quick Menu Setup to Perform Filtered PSD

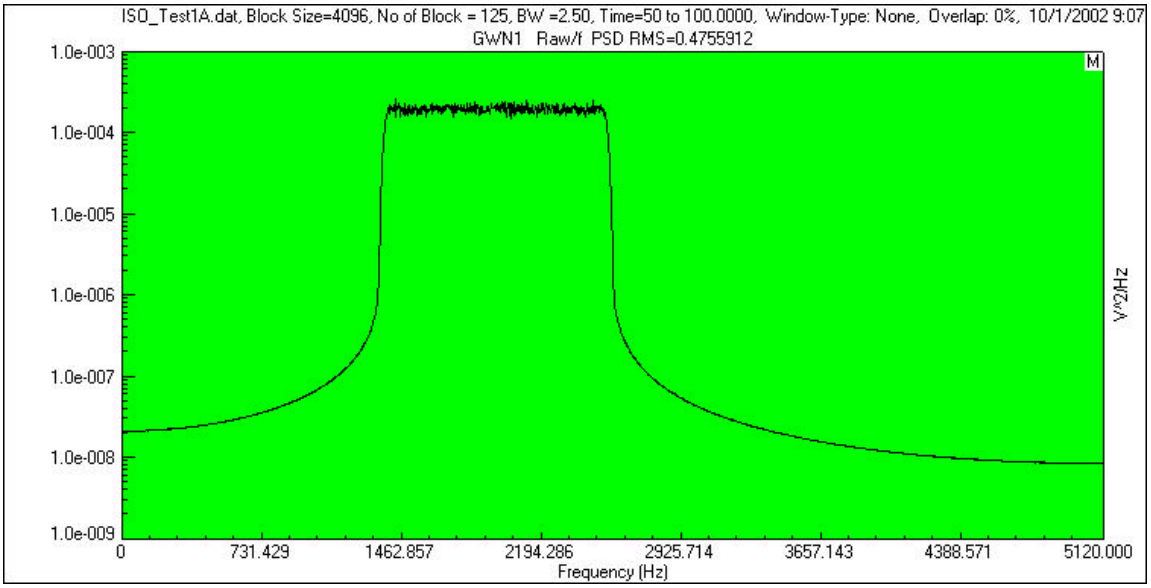


Figure 4.16 - Resulting Filtered PSD Plot

Function Window (Frequency Matching)

"Frequency Matching" function is implemented in PC Signal to enable users easily identify peaks. "Frequency Matching" requires a "Frequency Table." To setup a "Frequency Table," click right-mouse button and select "Frequency Matching Setup." "Frequency Matching/Marking Setup" window, figure 4.17 appears. Next click "New" to setup a new table. Enter "ISO_Test1A" as the name. Next another window, figure 4.18, pops up. This is where all the peak information is entered. To enter peak information, enter peak "Symbol," peak "Description," and its frequency, fixed or relative to reference frequency. Next check "Active" and click "Add." When a peak is not active, its frequency will not be matched with any peak found. Click "OK" when done.

For this example, "1x1" Function Window with a PSD plot for channel 1, block size of 4096, from 0 to 210 second is used. To use whole data file, click "Full." Click "Start" to begin processing. When resulting plot is shown, make sure correct Frequency Table is selected. Then select "Multiple Matching" -> "One Plot" to perform frequency matching. Resulting plot is shown in figure 4.19.

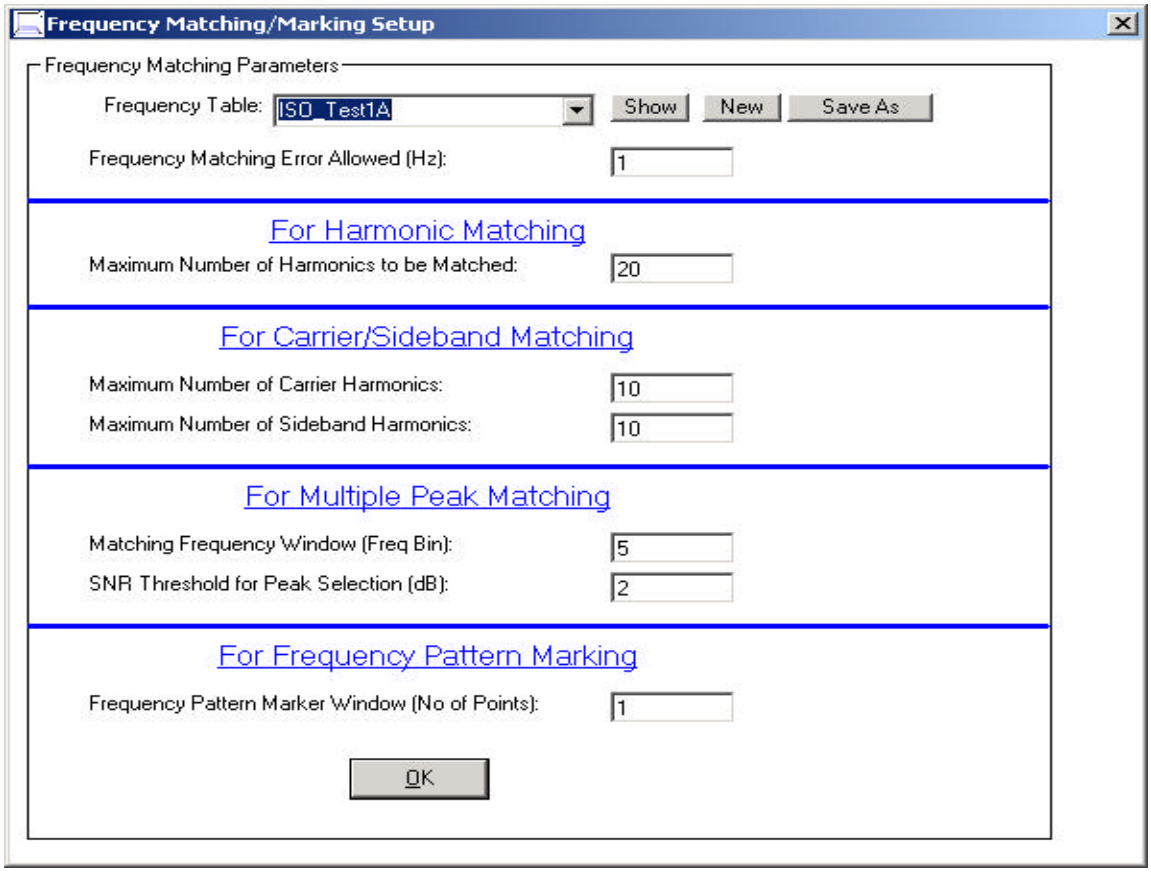


Figure 4.17 - Frequency Matching/Marking Setup

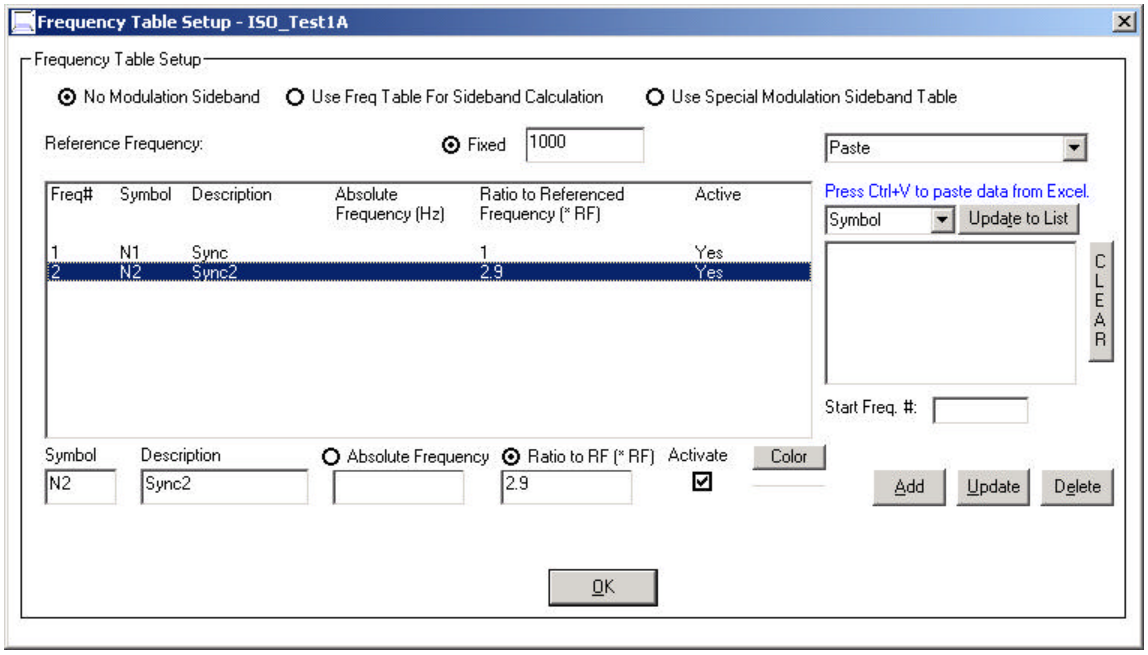


Figure 4.18 - Frequency Table Setup

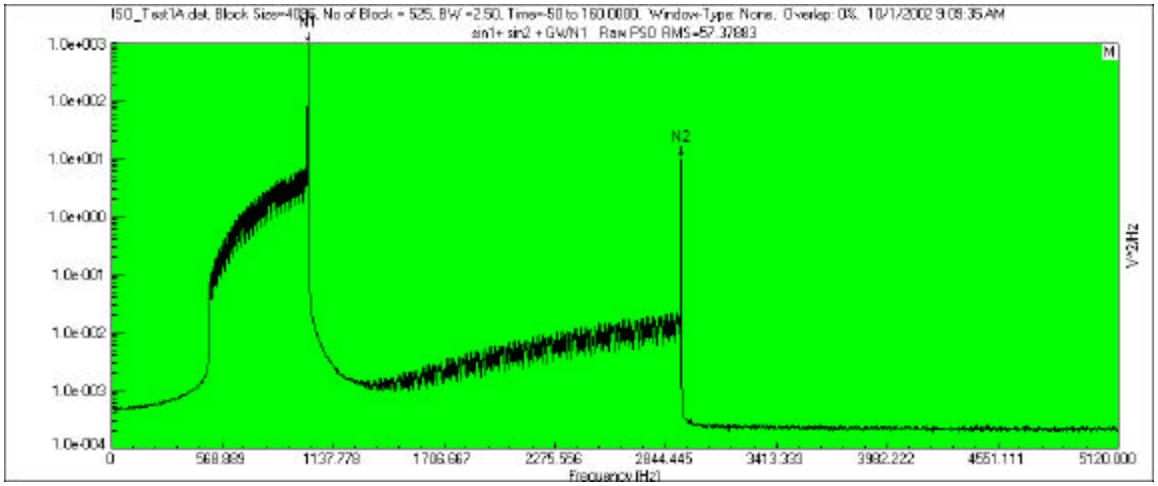


Figure 4.19 - Resulting Frequency Matching Plot

4.3 Function Window Button (Group)

Figure 4.20 shows a typical display of the "Function Window." The lower portion of the Function Window displays the resulting functions of signal processing. The top portion of the Window consists of a number of operation buttons which are grouped into the following 6 categories:

Function Window Button	Description of Function Window Button (Group)
Option	To select processing parameter, number of row/column for plotting, zoom, marker, basket, save, print, etc.
Quick	A quick way to select the same processing/function format for all channels.
Open/save Setting	To save/recall Function Window plot setting.
Processing Time Frame buttons group –	To select the processing time frame.
Time Moving button group	To move processing time frame within the data file time.
M-Menu	Menu of each sub-plot - To select signal processing & display for each individual sub-plot along with its plot format (color, x/y –axis range, linear/log, etc.) (to be discussed in section 4.3)

Table 4.2 - Description of Function Window Button (Group)

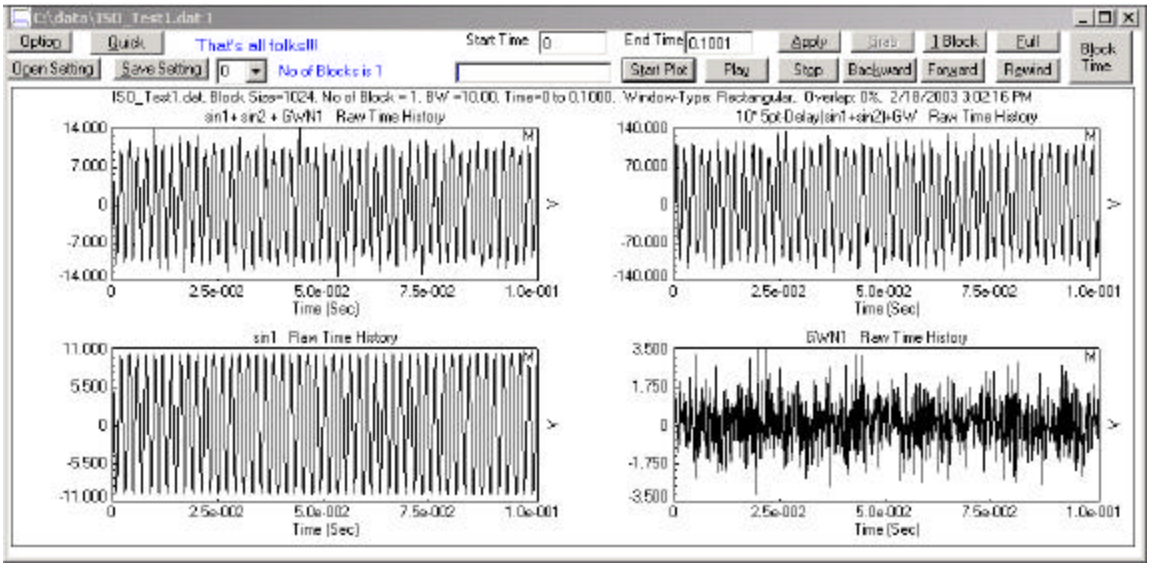


Figure 4.20 - Function Window Display

4.3.1 "Option" Button

This button is the same as a right-mouse click on any part of the Function Window. When the Option button (or the right mouse button) is clicked from the "Function Window," it opens a pop up option menu (figure 4.21). The Option button allows user to select processing parameter, number of row/column for plotting, zoom, marker, basket, save, print, etc. The description of each menu item is shown in Table 4.3.

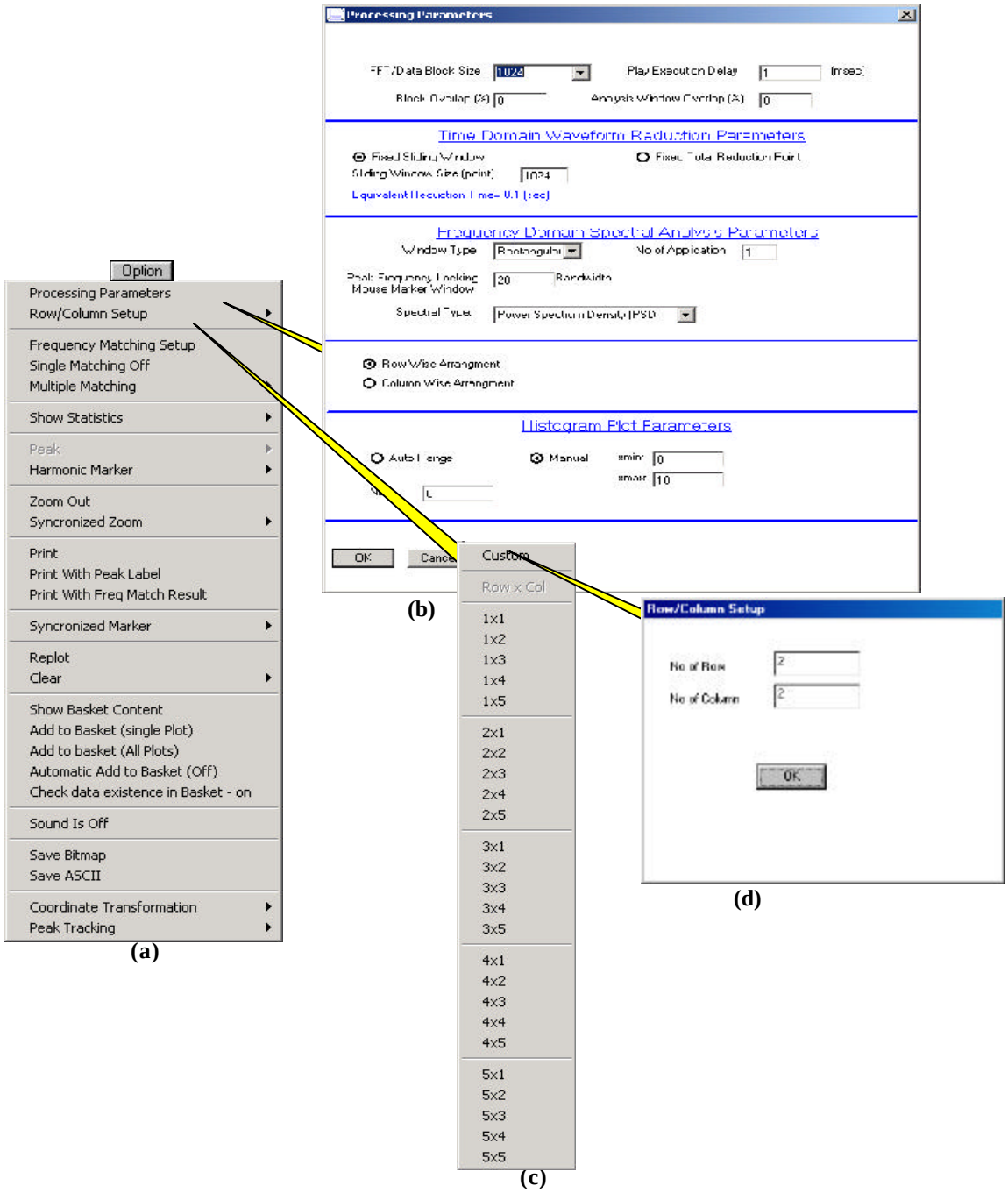


Figure 4.21 (a) Option (Right Mouse) Button Menu
(b) Processing Parameter Menu
(c) Row/Column Setup
(d) Custom row/column for page layout

Menu Item	Description of Menu Item in Option Button
Processing Parameters	The "Processing Parameter" menu allow user to select (1) FFT/Data Block size for spectral analysis, (2) Reduction Time for Waveform Reduction (3) Window application for spectral analysis. (4) Overlap for block processing (5) Peak frequency lock-in for mouse marker
Row/Column Setup	Specify the number of row and columns the current function window will have. See Figure 4-3c.
Frequency Matching Setup	Sets up the frequency table for frequency matching. Additional matching parameters are also set here.
Single Matching Off	When chosen, frequency matching for single peak is turned on. After this option is turned on, when left mouse button is clicked on a plot, the peak within "Mouse Marker Bandwidth" is located and its frequency is matched using existing parameters.
Multiple Matching	When chosen, frequency matching for all peaks is turned on. After this option is turned on, when left mouse button is clicked on a plot, the all peaks are located and peak frequencies are matched using existing parameters.
Show Statistics	When chosen, a new "Function Window" plot, containing the statistics of the current plot, pops up. The plot is in the form of a Histogram. Current or all plot statistics can be drawn depending on the selection. Figure 4.22 shows the resulting statistics plot of figure 4.20.
Peak	Display the list of peak that matches the criteria specified by the user. Figure 4.23 shows the resulting peak listing using 5 (SNR) and 10 (Freq Window).
Harmonic Marker	Marks the harmonics of the specified frequency that is within the range. Figure 4.24 displays the markings of 500 Hz.
Zoom Out	After "Zoom In", use this option to return to the original plot of overall x-range. Zoom in is accomplished by click, drag and release left mouse button.
Sync. Zoom	When chosen, synchronized zoom option will be turned on. This enables the user to zoom in to same range of frequency, or time, of all plots in the Function Window. It is equivalent to changing the maximum and minimum x-axis values of all plots to some value.
Print	Prints all plots in "Function" window.
Print with Peak Label	Prints all plots with peak frequency values.
Print with Frequency	Prints all plots with peak frequency values matched to existing parameters. Like "Multiple Matching" then "Print".
Synchronized Marker	When chosen, synchronized marker option will be turned on. This enables the user to compare plots from different graph boxes using same marker position.
Replot	This option will redraw the plots with updated configurations.
Clear	Clear the Function window.
Show Basket Content	Allows user to see what plot data are stored to be saved into file or further processing, Figure xx. See section yy for detail information on "Basket."
Add to Basket (Single Plot)	To add and store a single plot data within the "Function Window" into a basket file (to be recalled later for further processing).
Add to Basket	To add and store all plots data within the "Function Window" into a basket file

(All Plot)	(to be recalled later for further processing).
Automatic Add to Basket	When switched on, this option enables the user of PC Signal to add processed data, in the "Function Window," be added into the "Basket" automatically.
Check Data Existence	When switched on, this option adds processed data of the "Function Window" into the "Basket" without checking the existence of the same result in the "Basket."
Sound Off	When chosen, sound option is turned on, and the signal of selected plot will be played through PC's speaker allowing user to listen to the signal. See section 4.3.1.2 for more details.
Save Bitmap	Save the resulting plot into a bitmap file.
Save ASCII	Save a particular plot data into file in ASCII format.
Coordinate Transformation	Allows the user to transform coordinate from "Time" to "RPM," "Tau," etc. and back.
Peak Tracking	Used in conjunction with the "Play" button. When switched on, this option tracks the peak amplitude of the desired frequency and display the result in a separate window.

Table 4.3 - Option (Right Mouse) Button Menu Item Description

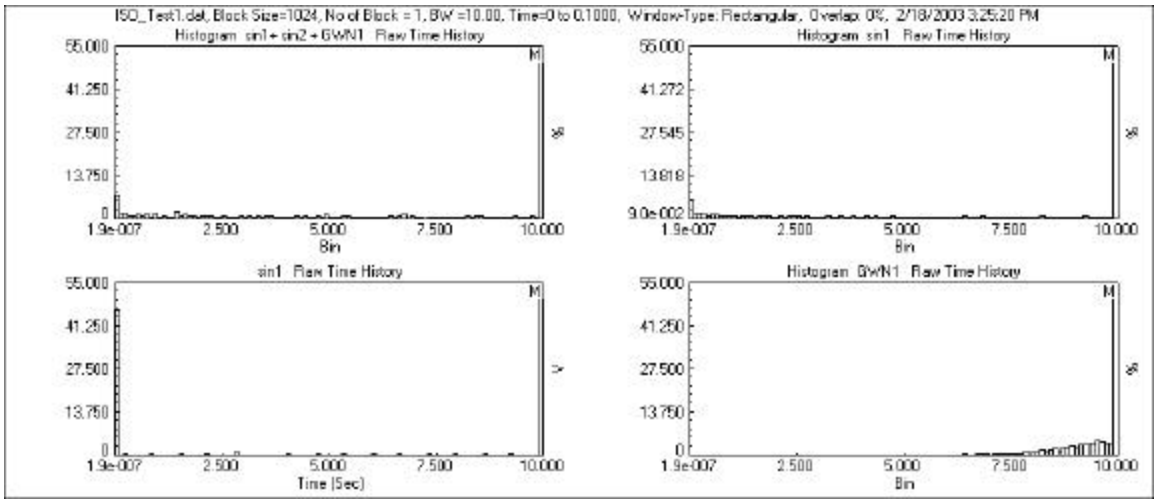

ISO_Test1.dat, Block Size=1024, No of Block = 1, BW =10.00, Time=0 to 0.1000, Window-Type: Rectangular, Overlap: 0%, 2/18/2003 3:25:20 PM
Histogram sin1 + sin2 + GWN1 Raw Time History
Histogram sin1 Raw Time History
sin1 Raw Time History
Histogram GWN1 Raw Time History
Bin
Time (Sec)

Figure 4.22 – Resulting Statistics Plot of Figure 4.20

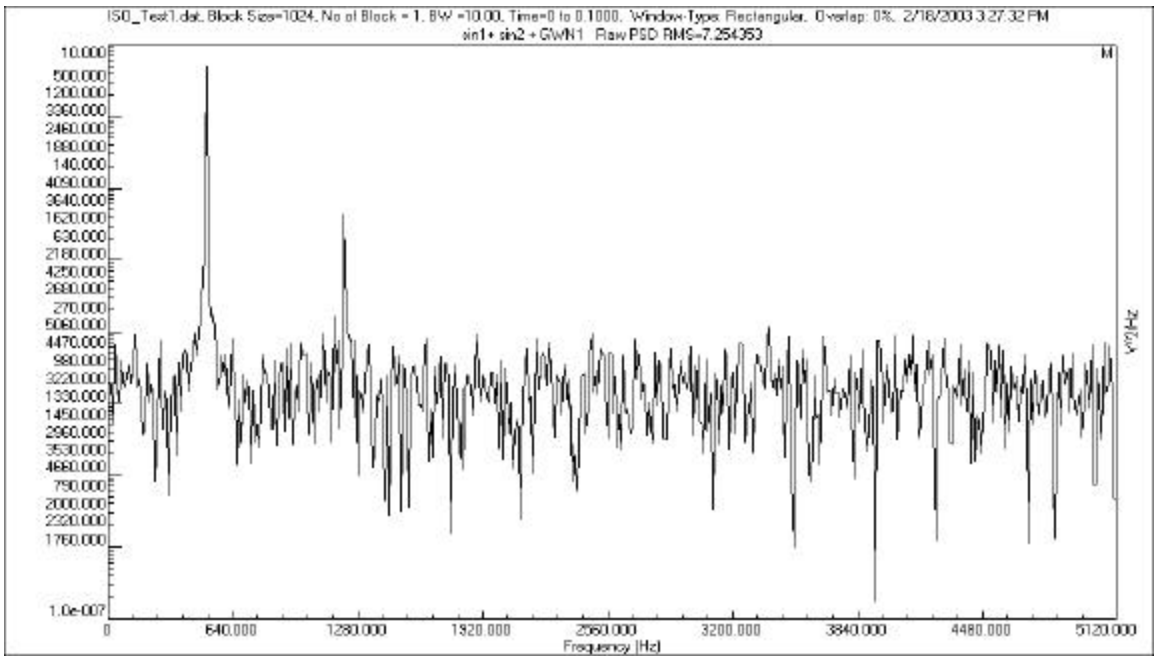


Figure 4.23 – Sample Peak List Plot

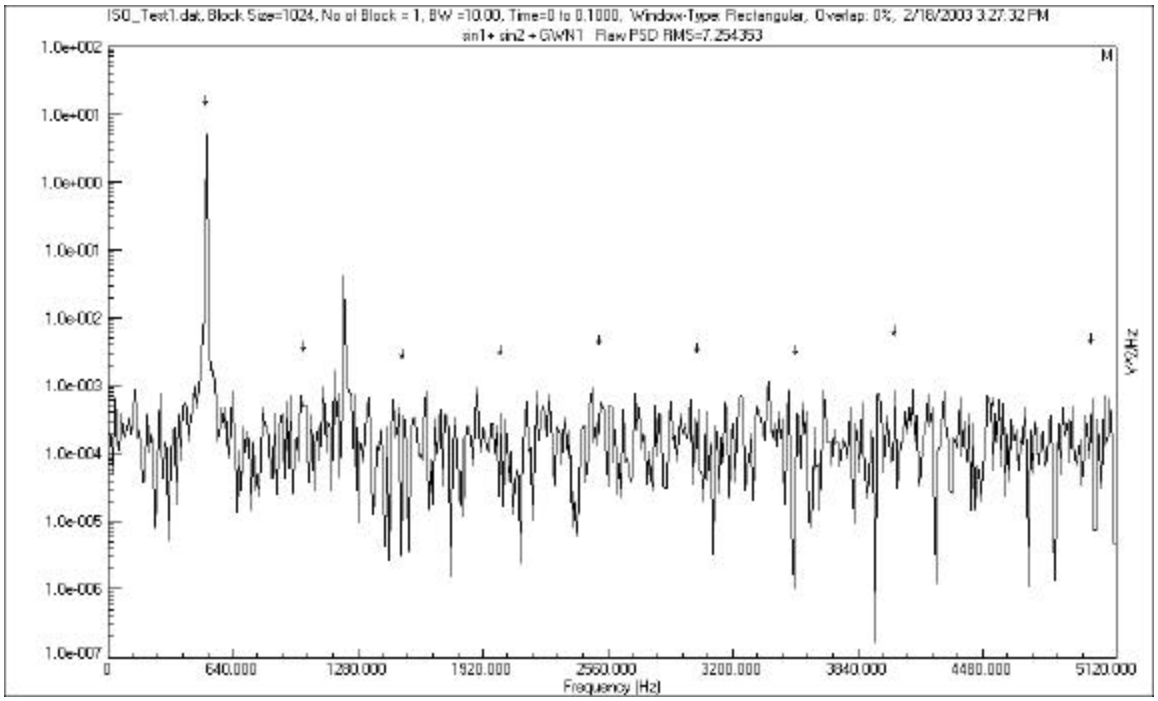


Figure 4.24 – Harmonic Marking of 500 Hz

4.3.1.1 "Processing Parameter" in "Option" Button

The "Processing Parameter" menu (See Figure 4.21b) allows the user to select/set the following parameters:

Parameter Name	Parameter Function
FFT/Data Block Size	FFT/Data Block size for processing
Play Execution Delay	This sets time delay between each block calculation, in msec, minimum is 1 and maximum is 32768.
Block Overlap(%)	This sets the percentage of overlap from one processing block to the next.
Analysis Window Overlap	This sets the percentage of overlap from one analysis window to the next. If analysis window is (0-5) sec and overlap is 50%, then next analysis window is (2.5-5) sec.
Fixed Sliding Window/Fixed Total Reduction	This option applies to the "Time Domain Waveform Reduction" processing only. "Fixed Sliding Window" reduces the time data into 1 point for the reduction set. "Fixed Total Reduction" reduces the time data to the fixed total number of points regardless of the size of input.
Window Type	Type of window: None, Flat Top, Hamming, Hanning, Kaiser Bessel, and Rectangular. – Applied to all spectral analysis
No of Application	For Multiple window application. – Applied to all spectral analysis
Peak Frequency Locking Mouse Marker Window	The range where the highest peak is to be searched from current mouse position. This is only used in finding peak. – Applied to frequency domain function display.
Spectral Type	This option sets the spectral types as "Power Spectrum Density," "Power Auto Spectrum," and "Auto Spectrum."
Row/Col Arrangement	This option applies to setting plots using "Quick" menu only. This option sets the row/column major plot channel assignment.
Histogram Plot Para.	This option is for use in "Statistics" display.

Table 4.4 - Processing Parameters in "Option" Button

4.3.1.2 "Sound" Option in "Option" Button

The user can enable this option, Spectrogram Waterfall Topo, and listen to the sound of raw data being processed. It can be selected in the Right Mouse Button option. When that option is switched on, figure 4.25, a sound menu appears. Once this menu is set, the user can listen to sound of data as the file is being processed. Parameters and their explanations for this menu are listed in the following table. When using the sound option in the "Function Window," turn the sound option on. When clicking on the sub-plot whose signal to be played, the menu symbol "M" of that sub-plot will turn into "S" to indicate the sound channel selection. To switch the sound to other channel, simply click on the next desired sub-plot.

Sound menu items	Description of Sound menu items
Gain	Gain of sound.
D/A Gate	Digital to audio gate. All parameters are in engineering unit.
xmax	Maximum x scale.
xmin	Minimum x scale.
Sound On/Off	Switches sound on or off
Sound Speed	Determines how fast sound will be played.
Auto Fast/Slow	PC Signal sets the speed.
Auto Fast/Real Time	PC Signal will play sound as fast as CPU can handle.
Manual	User sets the speed, in percentage.
OK	Confirms the settings.
Cancel	Discard the settings.
Apply	Update to current settings.
Open Menu	Open previously saved sound settings.
Save Menu	Save current settings.

Table 4.5 - Description of Sound menu items

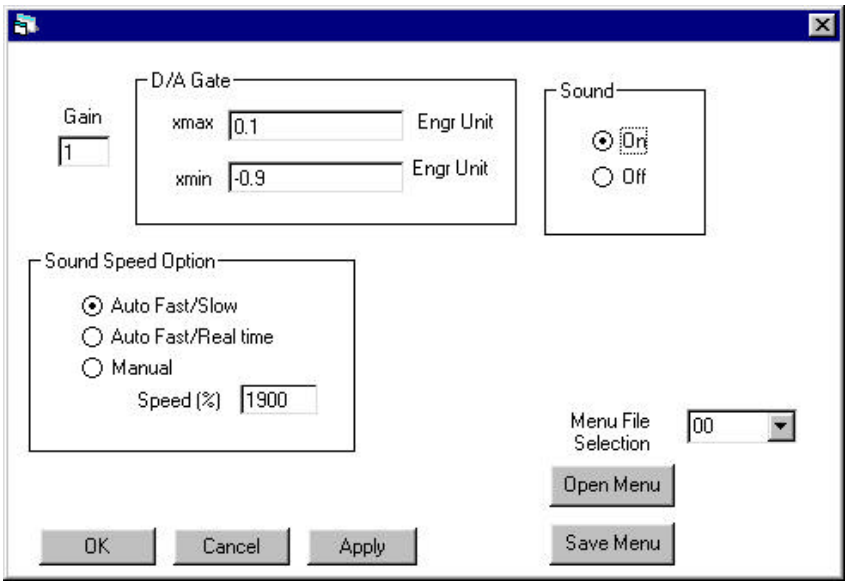


Figure 4.25 - Sound Setting Menu

4.3.1.3 "Basket" in "Option" Button

The "Basket" option allows user to save processed data arrays in a basket file, which can be recalled later for further processing. Typical operation procedure is described below:

1. To save all the plots currently being displayed in the "Function Window" into the "Basket," click "Option" (or right mouse button) and select "Add to basket (multiple plots)". All data plots shown in the "Function Window" will then be added and stored into a basket file (unnamed yet). A name for each plot (line) will be assigned based on its test_ID/Channel_ID/Signal/Function/Info for easy recognition during recall. This step of adding to basket can be repeated many times to add more plots into the basket during analysis.

2. To view all plots been saved in the basket, clicking on "Option" (or right mouse button) and select "View basket." A "Basket" menu page as shown in Figure 4.26 will be displayed. Clicking "Remove" will remove highlighted data from basket. Using "Save" to save the current basket to a basket file name.

3. To recall plot files stored in a basket file at a later time, clicking on "Option" (or right mouse button) and select "View Basket "and then use "Open" to open the desired basket file.

4. To plot the recalled plots in the basket file, first click on the desired sub-plot box, (user might need to clear this sub-plot box). Then choose the desired plot name in the basket file list by highlighting it, and then click "Add to Plot" button. The recalled plot will now be displayed in the selected sub-plot box. More than one plot can be placed in the one sub-lot box.

Each data in the basket can further be manipulated by using "Add" button. A combination of data in the basket can be obtained by highlighting data, setting "Factor" and clicking "Add." This is similar to "Multiple Lines Multiple Functions" in M-Menu of "Function Window." Click "Remove" to remove a particular line from the plot in "Block Manipulation." "Reset" removes all data. "Add to Plot" draws graph of manipulated block.

Parameter Name	Description of Basket Menu Items
Reset	Removes all data from the Basket.
Save	Stores data the basket into a selected basket file.
Open	Allows user to retrieve previous baskets.
Add to Plot	This option will plot selected data in the last mouse-clicked graph box.
Add All	This option will plot selected data in the "Function Window" one line in each sub-plot box.
ASCII File	Saves the data in the "Basket" into an ASCII file.

Excel File	Saves the data in the “Basket” into an Microsoft Excel file.

Table 4.6 - Description of Basket Menu Items

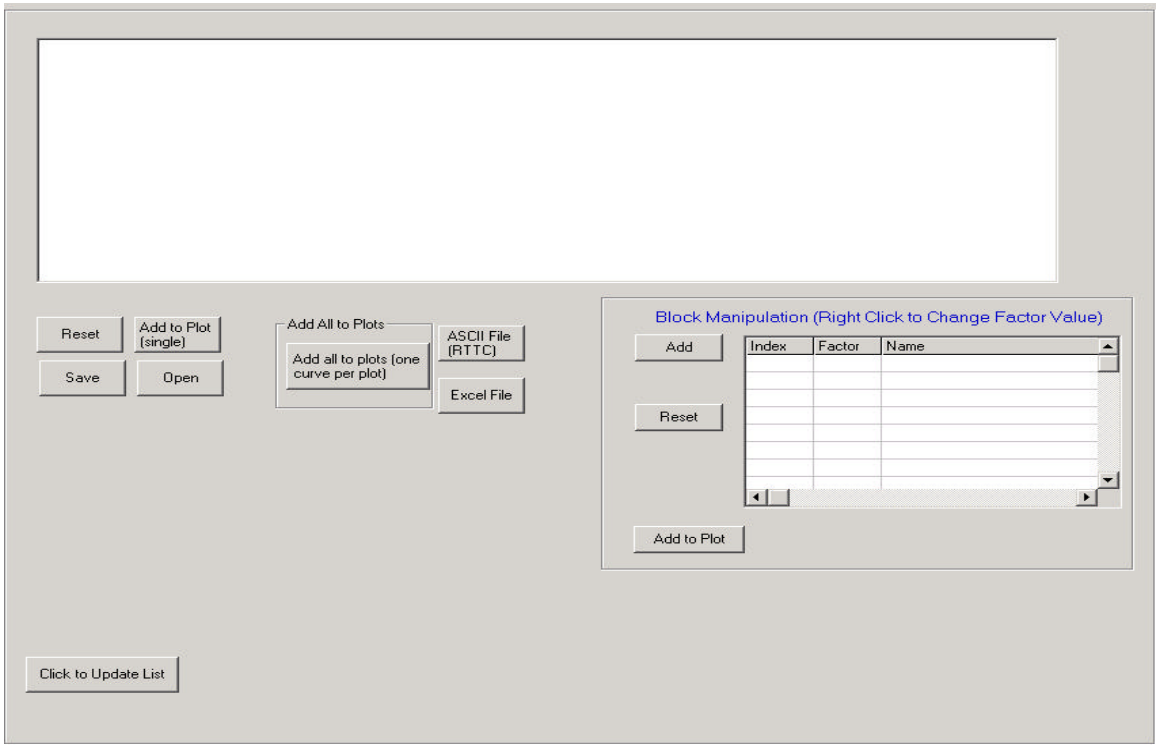


Figure 4.26 - Basket Window

4.3.2 Quick

This option allows users to setup page settings quickly by setting the same processing function for multiple channels. When "Quick" button is clicked, the following window (figure 4.27) appears.

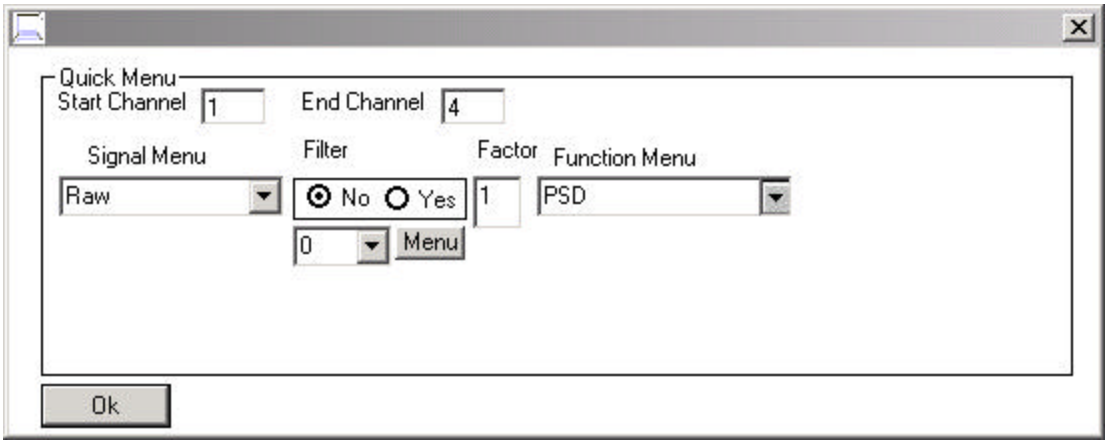


Figure 4.27 - "Quick" Menu

Explanation of each Quick menu item is as follows:

Menu Item	Description of Menu Item in Quick Button
Start Channel	Starting channel number for use in Function Window setting.
End Channel	Ending channel number for use in Function Window setting..
Signal	Type of signal to be used in processing data. (same as table 4.1-1)
Filter	Filter parameters to be used in data processing. (same as table 4.1-1)
Function	Type of function to be used in data processing. . (same as table 4.1-1)
OK	Confirms the current settings. To cancel, click "x" at top right hand corner of window.

Table 4.7 - Quick Button Menu Item Description

The channel arrangement is governed by the "Row/Column Arrangement" selection in the "Processing Parameters."

4.3.3 Open/save setting

After user set up the various plot formats within a Function Window (such as a 3row by 3 column plot with 1st column showing time histories, 2nd column showing PSDs; 3rd column showing Histograms), the setting can be save to a "Function Window Setting

Menu" which is recorded as a menu number. Such saved page setting can then be recalled for future usage without having to repeat the setup process again.

4.3.4 Processing Time Frame (PTF) buttons Group

The Processing Time Frame Buttons Group allows the user to select the processing time frame as described in table 4.8.

Note: Since the Function Window will perform either block-by-block processing or multiple-block averaging, the user-selected Processing Time Frame will be automatically truncated to the smaller block time near the PTF. (Block size is set in the "Processing Parameters" window, discussed in section 4.3.1)

Item	Description of Menu Item in Quick Button
Apply	To manually select a time frame: Enter the desired times in the start/end time box and then click the "Apply" button.
Grab	To Grab the selected time in the Reference Window: (Needs to use in conjunction with Reference Window). First select the desired time period in the Reference Window by dragging the mouse pointer directly over the reduction waveform, and then click the "Grab" button in the Function Window
1-Block	To choose a time frame with 1 block length: First select the desired start time either using "Apply" or "Grab", then click the "1-Block" button. . It value of block size is set by "FFT/Block Size" in the Option Button (see section 4.2.1) Start time will remain the same. End time is obtained by adding the quotient (of block size divided by sampling frequency) to the start time.
Full	To choose the time frame of the entire test data by click the "Full" button.

Table 4.8 - Time Frame buttons Group Menu Item Description

4.3.5 Time Moving Button Group

The time moving button group allows user to move processing time frame within the data file time as described in table 4.2-8.

Start Plot	Starts data processing and display the result without continuously advancing to the next time frame. (i.e. plot and freeze with not animation or update)
Play	Start data processing and display the result one time frame at a time and continuously updates by advancing to the next time frame. The next time frame will have the same duration but with its Start Time equals to the end

	time of current time frame. Animation display is shown with old graphs being overwritten when new data is processed and ready to be graphed.
Stop	Stop data processing and advancing.
Forward	Advance one time frame and process/display without further advancing
Backward	Move back one time frame and process/display without further action.
Rewind	Goes processing time frame back to the start of data file.

Table 4.9 - Time Moving Button Group Menu Item Description

The horizontal bar appeared in the middle of window indicates where the current block located, with respect to the whole data file. When Reference Window is activated, the current processing time frame will also show as a moving bar on Reference Window's reduction waveform. The feature allows the user to correlate the timing of information displayed in Function Widow to the overall test profile.

4.3.6 M- Menu in Function Window

As discussed in section 4.3.2, the Quick option allows users to setup page settings quickly by specifying the same processing function for multiple channels. If user needs to set up different processing function for multiple channels, it can be achieved using the M-Menu of each sub-plot. By clicking "M" at the top right corner of each sub-plot box, an "M" menu page appears, Figure 4.28. Settings for individual sub-plot are done here. The descriptions of each menu item in the "M" menu Page are listed in table 4.9.

4.3.6.1 Single-Line Option

When Single-Line Option is selected in the M-menu page, there will only be one function displayed (represented by one plot line) within each sub-plot. The function displayed is defined by the selection in the signal/filter/function/channel menu group.

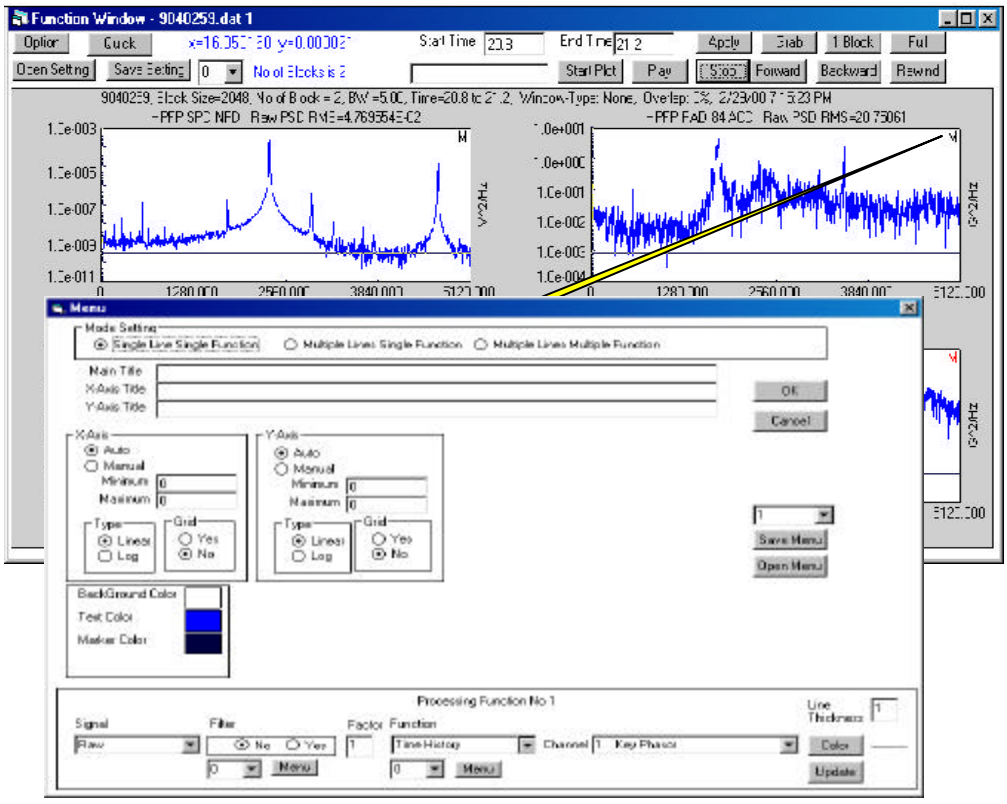


Figure 4.28 - "M" Menu Page of each sub-plot (Single Line Option)

4.3.6.2 Multi-Line Option

The Function Window is capable of drawing multiple lines within sub-plot(s). In "Multiple Line-Single Function" mode, (figure 4.29) more than one type of signal will be drawn in a single sub-plot box. Settings are the same as in "Single Line Single Function" mode. The user will have to determine how many lines are to be drawn in a particular sub-plot box and what they will be by entering "No of Lines." Choosing "Line 1", "Line 2" etc. allows the user to set each line's plot format through the same signal/filter/function/channel menu group. To confirm each line of the graph, the user needs to press "Update." If it's not pressed, the settings for that particular graph will not be updated.

Menu Item	**Menu Item Description of "M" Menu of each sub-plot**
Main Title	Sets main title of graph.
X-Axis Title	Sets X-title of graph.
Y-Axis Title	Sets Y-title of graph.
Auto	Sets auto scaling for X and Y-axes.
Manual	Sets scaling for X and Y axes manually.
Type	Sets linear or Log_{10} scale graph.
Grid	Draws grid of graph in background if chosen.
Colors	Sets background, text, and marker colors.
Signal	Type of signal to be used in processing data. (same as table 4.1-1)
Filter	Filter parameters to be used in data processing. (same as table 4.1-1)
Factor	Scalar multiplier of signal. (same as table 4.1-1)
Function	Type of function to be used in data processing. . (same as table 4.1-1)
Channel	Sets the channel to be processed. (same as table 4.1-1)
Color	Sets color of line of graph to be drawn.
Update	Confirms each line setup. In "Single Line Single Function" this option can be skipped.
OK	Closes "Menu Page". In "Single Line Single Function" it also means confirms current line setup.
Cancel	Discards changes.
Print Form	Prints "Menu Page" image.
Save Menu	Save current menu setting to a menu #
Open Menu	Open an exiting menu of the selected menu #

Table 4.9 - "M" Menu Item Description of each sub-plot

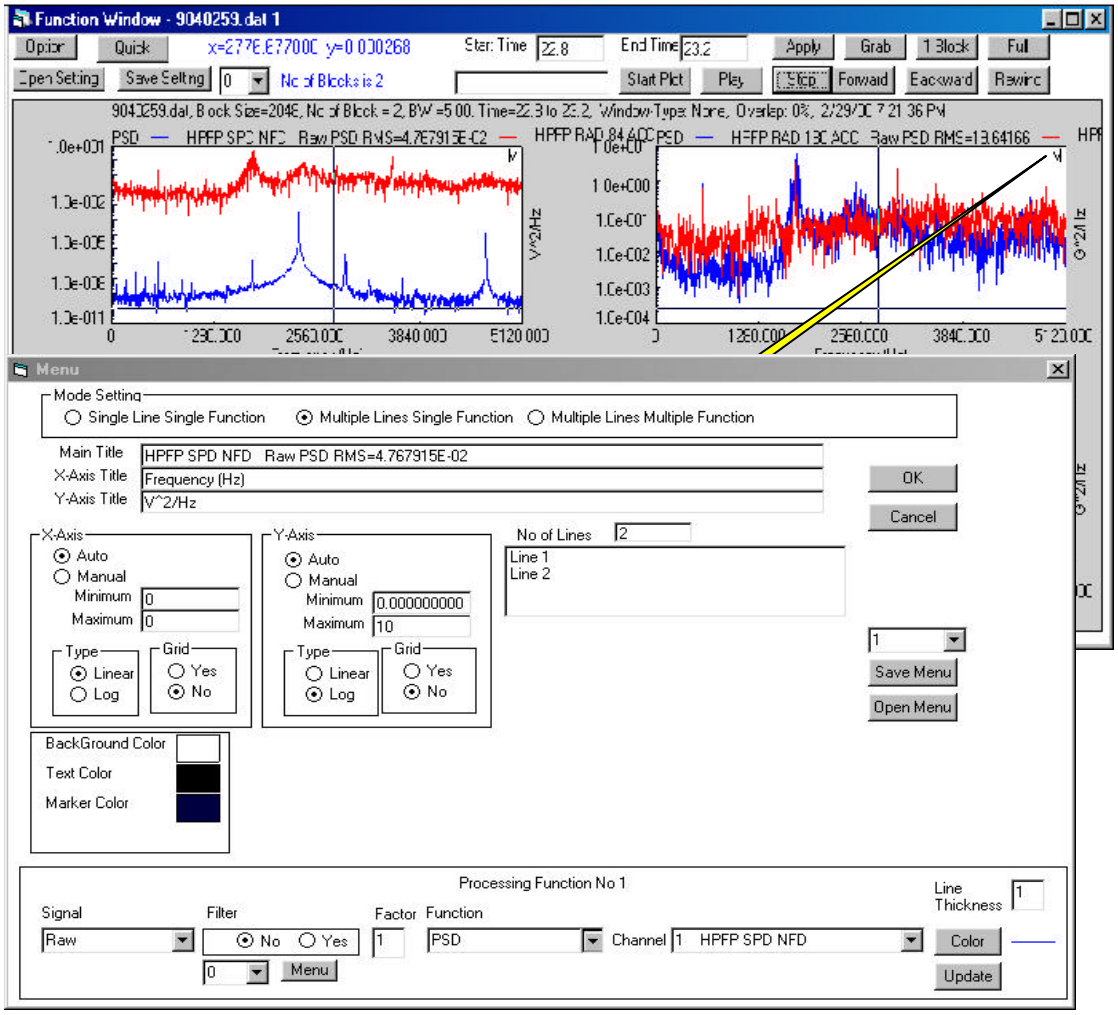


Figure 4.29 - "M" Menu Page of each sub-plot (Multi-Line Option)

5.0 3D Plot Window Parameters

The 3D window under "Signal Processing" Main menu allows the user to display 3D Spectrogram, Waterfall or 3D Bi-Coherence graphs. Click on "Signal Processing", and choose "3D Window", a 3D Window menu page as shown in Figure 5-1 will pop up. By entering on appropriate menu items, and clicking "Start," PC-Signal will start the 3D processing and display. Explanation of common menu items for 3D plot is delineated in the following table.

Parameter Name	Parameter Function
Plot Format	Allows user to choose format of 3D plot by checking on desired plot type. (Spectrogram, Waterfall or Bi-Coherence).
Signal	Type of signal to be used in processing data. (Same as table 4.1)
Filter	Filter parameters to be used in data processing. (Same as table 4.1)
Factor	Scalar multiplier of signal. (Same as table 4.1)
Function	Type of function to be used in data processing. (Same as table 4.1)
Channel	Sets the channel to be processed. (Same as table 4.1-1)
Start Time	Start time for processing data.
End Time	End time for processing data.
Block Size	FFT size. After FFT size is set, PC Signal will automatically display total number of blocks available for the current file for reference.
Window Type	Type of window for PSD: None, Flat Top, Hamming, Hanning, Kaiser Bessel, and Rectangular.
No of PSD Avg.	Number of FFT blocks to be averaged over for each PSD line.
X-axis	Selects automatic or manual x-axis values.
Active Plots	It allows user to view Time History, PSD, or Tracking when each line/function of the 3D plot is being displayed. It also allows user to listen to sound of the data being processed (see next row). To activate those options, check the box(es) of these options
Sound Menu	Sets sound menu parameters.
Update	Update current settings.
Cancel	Quit Time-Frequency window.
Start	Start processing selected plots.
Stop	Stop the process.
New One	Open a new window for processing.
Open Menu	Open previously saved settings.
Save Menu	Save current settings.
Batch Menu	Allows user to process different channels using same settings.
Start Channel	Starting channel to batch process Spectrogram, Waterfall, Topo, or 2D Bi-Coherence.

End Channel	Ending channel for batch processing.
Start	Start batch processing.
Stop	Stop batch processing.
Print	If checked, PC Signal will print the plot.
Save	If checked, graph will be saved.

Table 5.1 - Description of common Menu Items for 3D plot

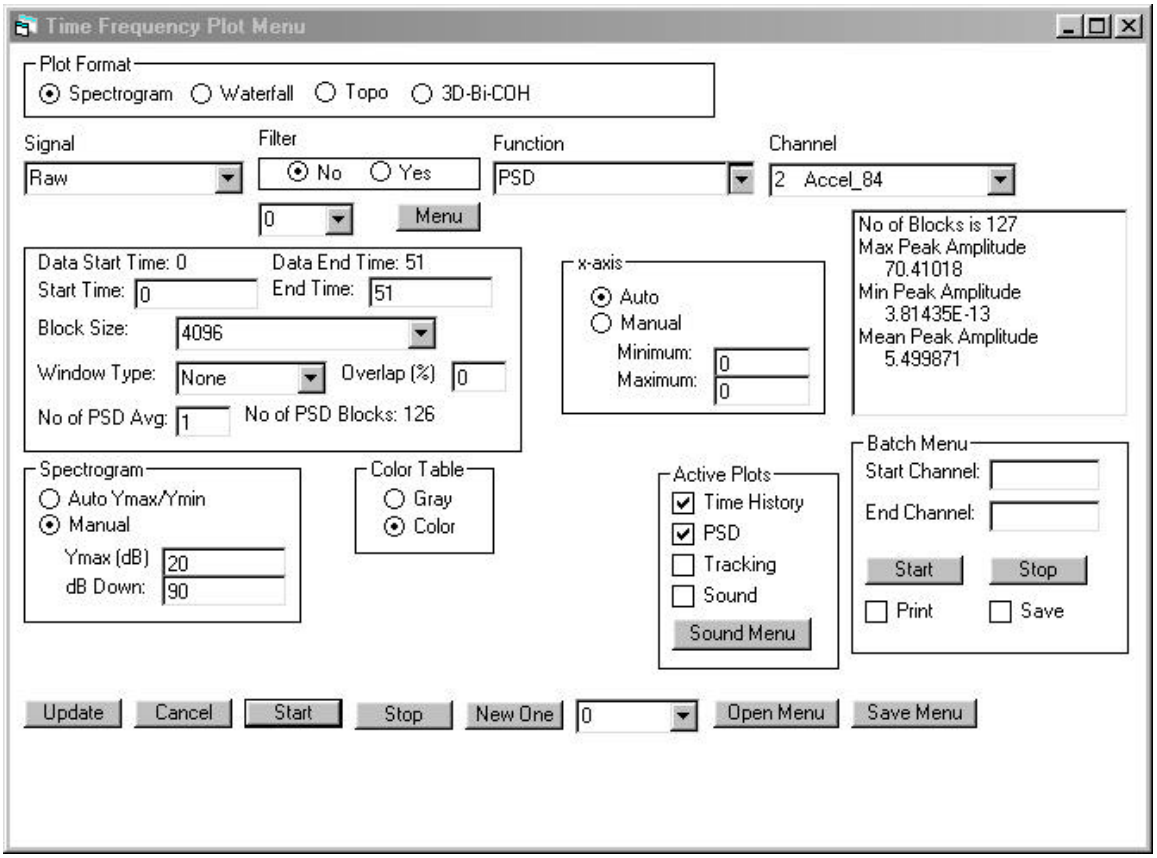


Figure 5.1 - Spectrogram Menu Page

5.1 Spectrogram

This option allows a user of PC Signal to draw Spectrogram, which display PSD of the chosen channel as a function of time and frequency. The amplitude range of the PSD to be displayed is specified by the "Ymax/Ymin" and is indicated by the amplitude scale color bar on the right of the page. Table 5-2 explains the remaining menu item that applied to Spectrogram. Figure 5-2 shows an example of Spectrogram plot.

Menu Items	Spectrogram Menu Items
Auto Ymax/Ymin	Either manually set the minimum and maximum values for y (amplitude), or automatically determined using the "Auto" mode.
Manual	Manually set the minimum and maximum values for y (amplitude) by specifying the Ymax (in dB) and Ymin (dB down from Ymax).
Color Table	Select whether the data are displayed in gray scale or in color.

Table 5.2 - Spectrogram Menu Items

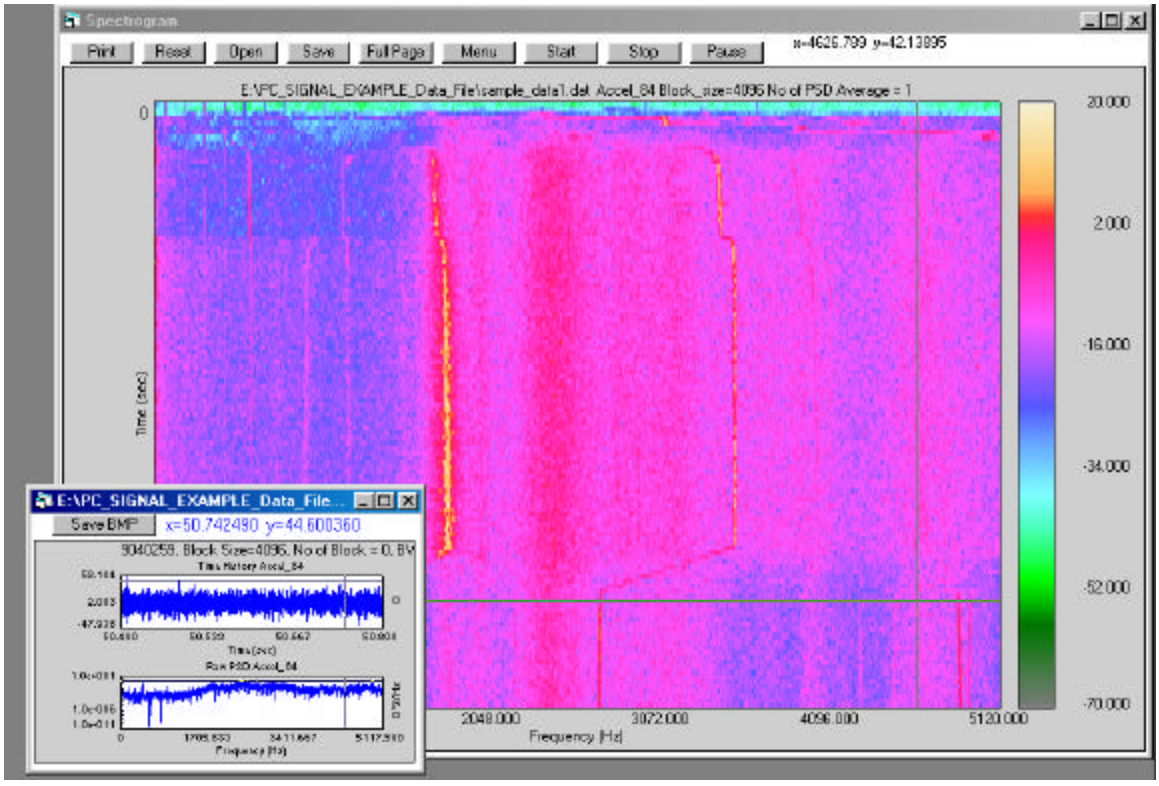


Figure 5.2 - PSD Spectrogram Plot

5.2 Waterfall

This option allows a user of PC Signal to draw PSD waterfall plot, which display PSD of the chosen channel as a function of time and frequency. The following table explains the remaining menu item that applied to waterfall.

Menu Items	Waterfall Menu Items
Manual Ymax/Ymin	User enters the PSD amplitude range by specifying the maximum y value (in dB) and minimum y value as dB down from Ymax. All PSD beyond this Ymax/Ymin range will be truncated in the waterfall display.
Auto Ymax/Ymin	Let PC-Signal sets maximum and minimum y values automatically for the1st PSD.
Skewness	Skewness of y-axis (in degrees).
Y-range of Sub-Plot(%)	Percentage of each individual PSD plot over the entire waterfall page.
# of PSD/Page	Total number of PSDs to be displayed in one waterfall page.

Table 5.3 - Waterfall Menu Items

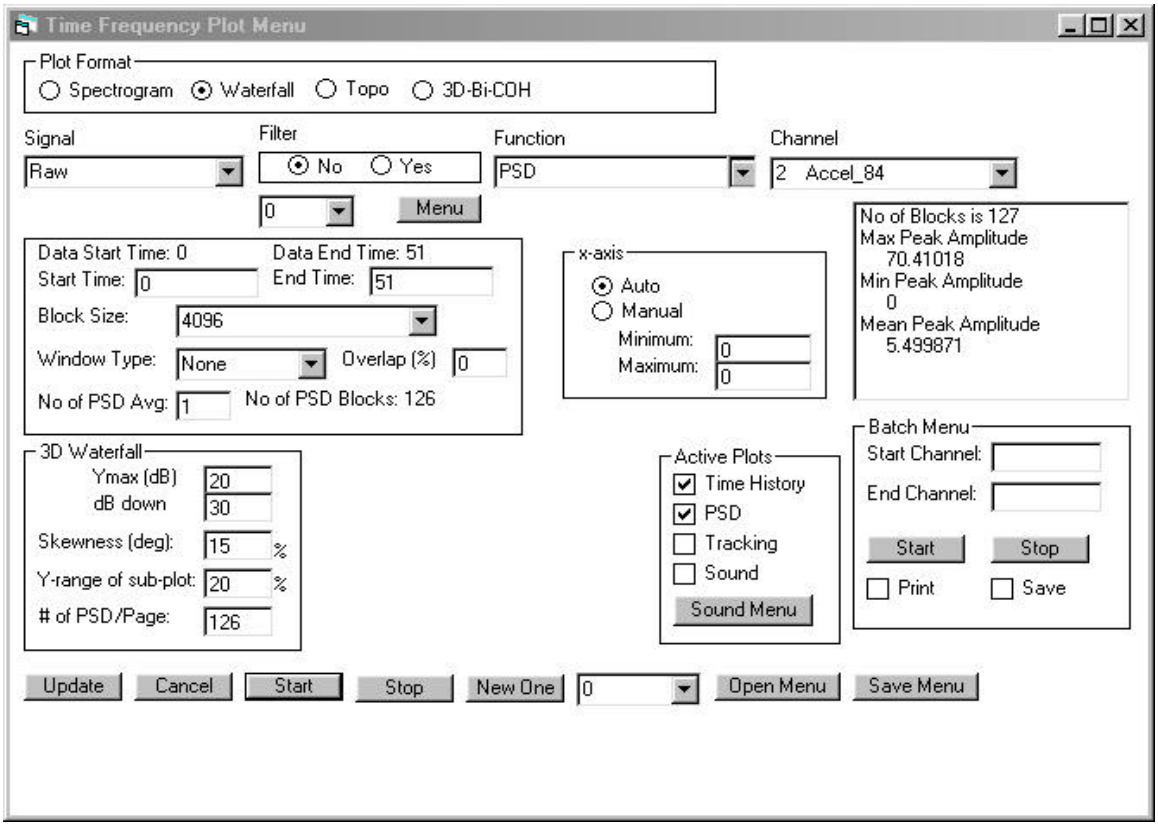


Figure 5.3 - Waterfall Menu Page

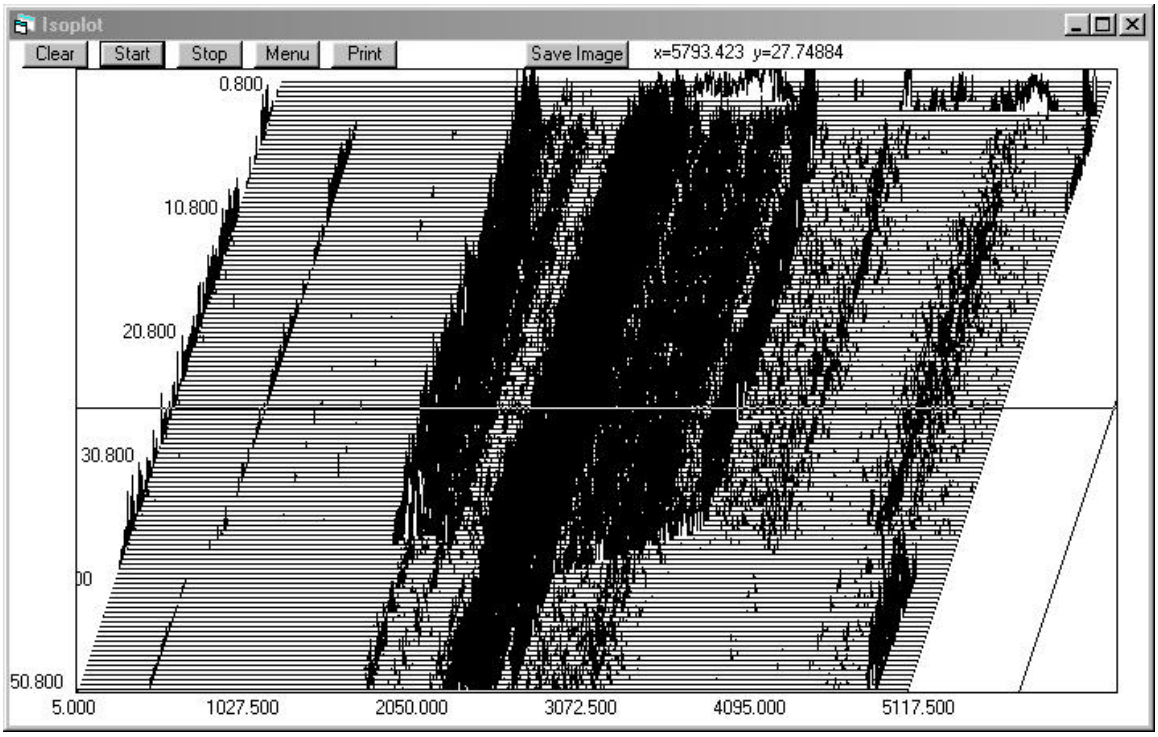


Figure 5-4 PSD Waterfall Plot

5.3 3D Bi-Coherence (Advanced Module Only)

This option allows a user of PC Signal to draw 3D bi-coherence function, $b_{xxx}(f_1, f_2)$, the chosen channel as a function of 2 frequencies (f_1, f_2) (reference to Technical Section). The following table explains the remaining menu item that applied to bi-coherence.

Menu Items	3D Bi-Coherence Menu Items
Start Frequency (f2)	Start frequency of f2 (y-axis) for Bi-Coherence processing (Note: the x-axis in the 3D bi-coherence plot represent the 1st frequency argument f1).
End Frequency (f2)	End frequency of f2 for Bi-Coherence processing.
Color Table	Sets graph color, gray scale or color.

Table 5.4 - 3D Bi-Coherence Menu Items

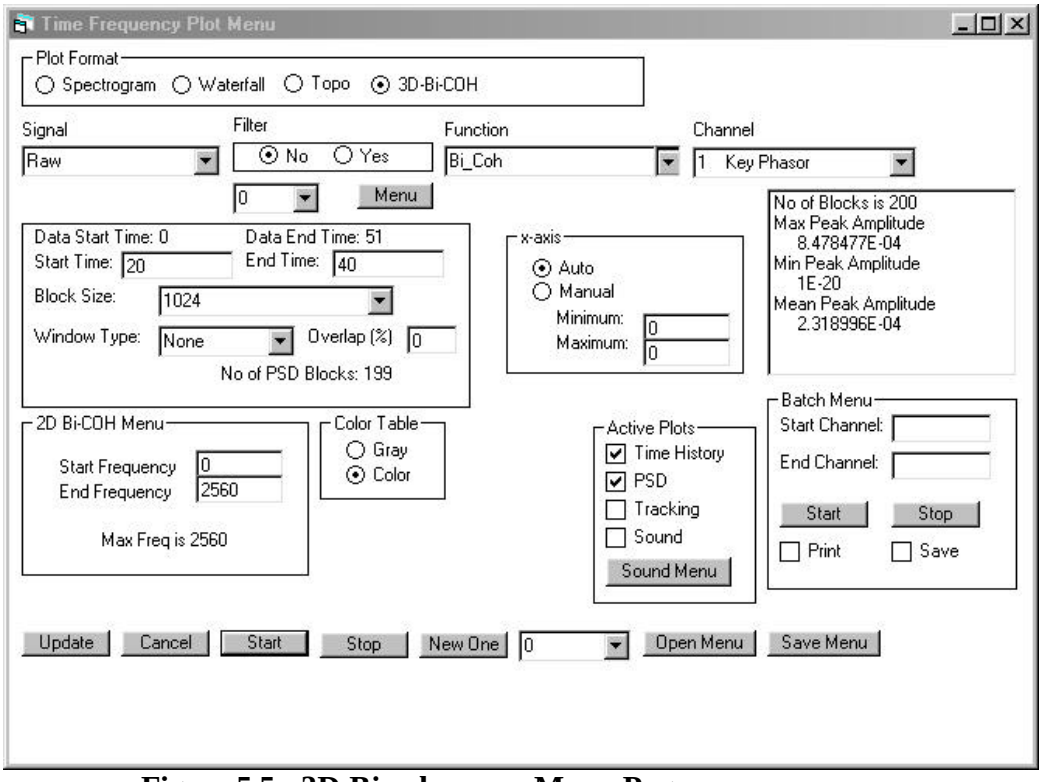


Figure 5.5 - 3D Bi-coherence Menu Page

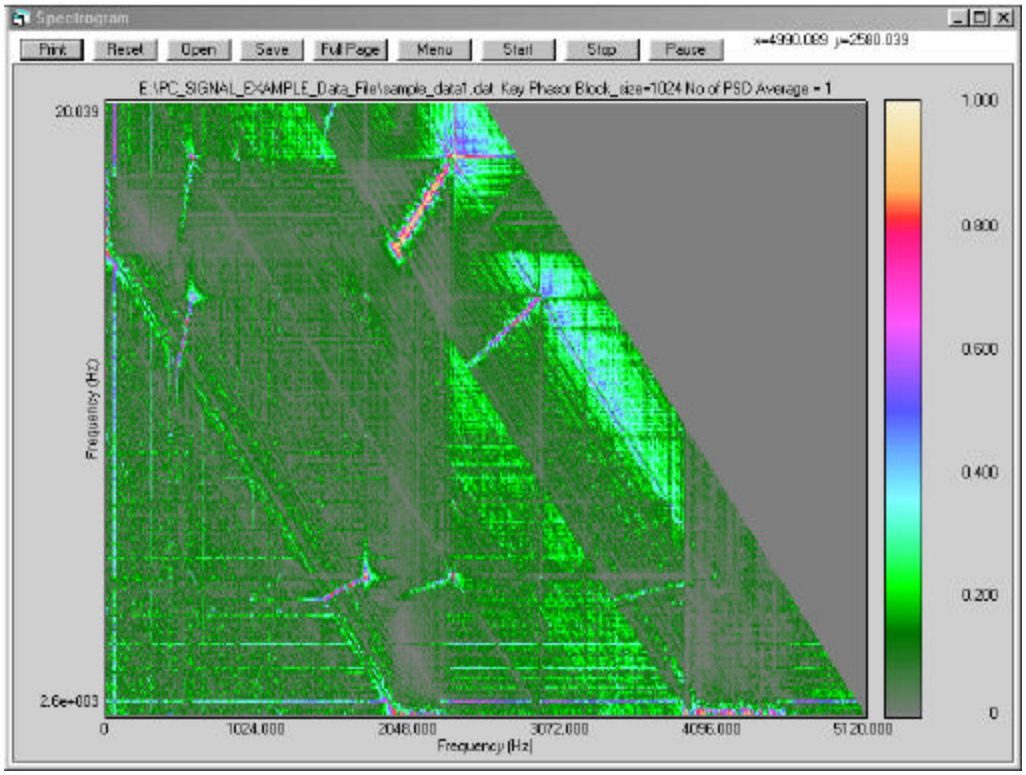


Figure 5.6 - 3D Bi-coherence function

6.0 Generate Data

"Generate Data" allows user to perform various signal processing of an opened data file and store the results in an output data file.

6.1 Generate Filter Data

This option allows the users to filter an input data, and generate an output filtered data file. Description of Generate Filter Data Menu items is listed in table 6-1.

Procedure for Generate Filter Data:

1. Click "Generate Data" Main menu item, and select "Generate Filtered Data," a menu page as shown in figure 6.1 will popup.
2. Select input data file to be filtered from "Input File" using "Browse" button. Header information of the selected file can be view from the "Header" button.
3. Select output data file from "output File" using "Browse" button. Header information of the output file will be automatically created which can be view from the "Header" button.
4. Selected channels of input file to be filtered in the "Available Channels" box by highlighting the desired channels from the input channel list and click "Add." To remove a channel from the output list, highlight and click "Remove." The selected channels will then be shown on the "Chosen Channels" box.
5. Select the filter characteristics either by directly entering the 3 boxes for "Filter Order," "Low cutoff," and "High cutoff," or from the menu page of "Show Filter" as discussed in Section 4.1.
6. Select the star/end time for filtering from the "Start Time" and "End Time" boxes.
7. Select the block size (e.g. 4096) for filtering processing from the "Block Size" box.
8. To save current settings for future use, choose appropriate number from drop-down "Menu" list and click "Save." Selecting a menu number and clicking "Open" will retrieve previously saved filter settings.
9. Click on "Start" to start the filtering process. Click "Stop" to stop the process.

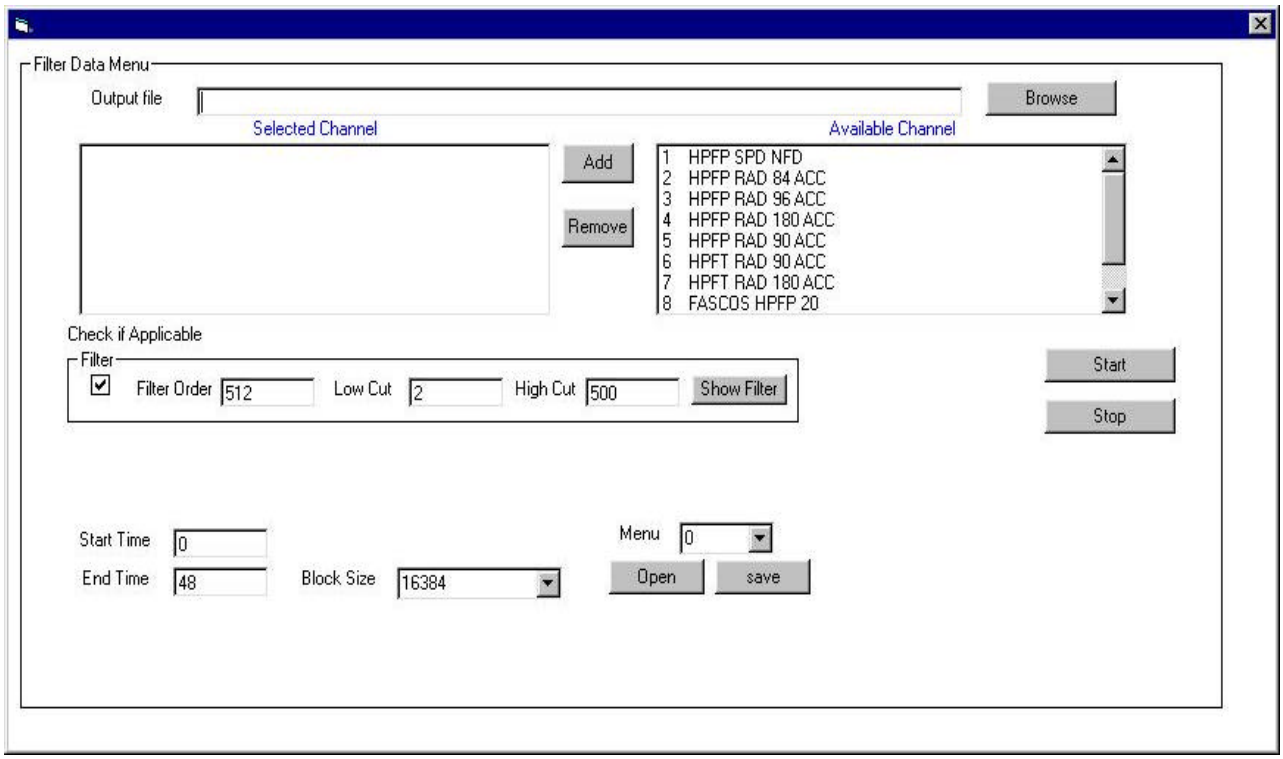


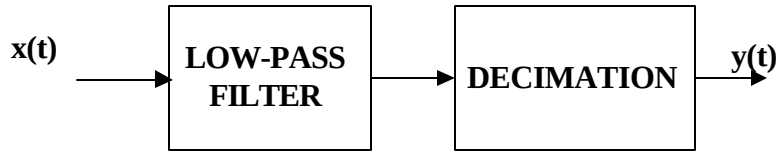
Figure 6.1 - Generate Filter Data Menu Page

Parameter Name	Parameter Function
Input File	Name of input file for processing
Output File	Name of output file for processing.
Available Channels	Name of channels available in the input file for processing..
Selected Channels	Channels to be processed for output.
Filter Order	Size of filter to be used in filtering process.
Low Cut	Low cut frequency of filter to be used.
High Cut	High cut frequency of filter to be used.
Start Time	Starting time of data to be used for filtering.
End Time	Ending time of data to be used for filtering.
Block Size	Block size to be used in filtering.
Menu	Menu number used to save current filtering parameters.

Table 6.1 - Description of Generate Filter Data Menu items

6.2 Generate Decimation Data

This option allows the users to down-sample an input data using low-pass filter/ decimation processing as shown below.



Procedure for Generate Decimation Data:

1. Click "Generate Data" Main menu item, and select "Generate Decimation data," a menu page as shown in figure 6.2 will popup.
2. Select input data file to be decimated from "Input File" using "Browse" button. Header information of the selected file can be view from the "Header" button.
3. Select output data file from "Output File" using "Browse" button. Header information of the output file will be automatically created which can be view from the "Header" button.
4. Selected channels of input file to be processed in the "Available Channels " box by highlighting the desired channels from the input channel list and click "Add." To remove a channel from the output list, highlight and click "Remove." The selected channels will then be shown on the "Chosen Channels" box.
5. Select the Pre-Decimation filter characteristics either by directly entering the 3 boxes for "Filter Order", "Low cutoff", and "High cutoff", or from the menu page of "Show Filter".
6. Select the star/end time for filtering/decimation from the "Start Time" and "End Time" boxes.
7. Select the block size (e.g. 4096) for filtering processing from the "Block Size" box.
8. Enter the desired down-sampling factor (must be an integer) in the "Decimation factor" box.
9. To save current settings for future use, choose appropriate number from drop-down "Menu" list and click "Save." Selecting a menu number and clicking "Open" will retrieve previously saved filter settings.
10. Click on "Start" to start the filtering process. Click "Stop" to stop the process.

Note: The higher cutoff frequency in filter must be smaller than:
(sampling frequency)/(2*decimation factor)

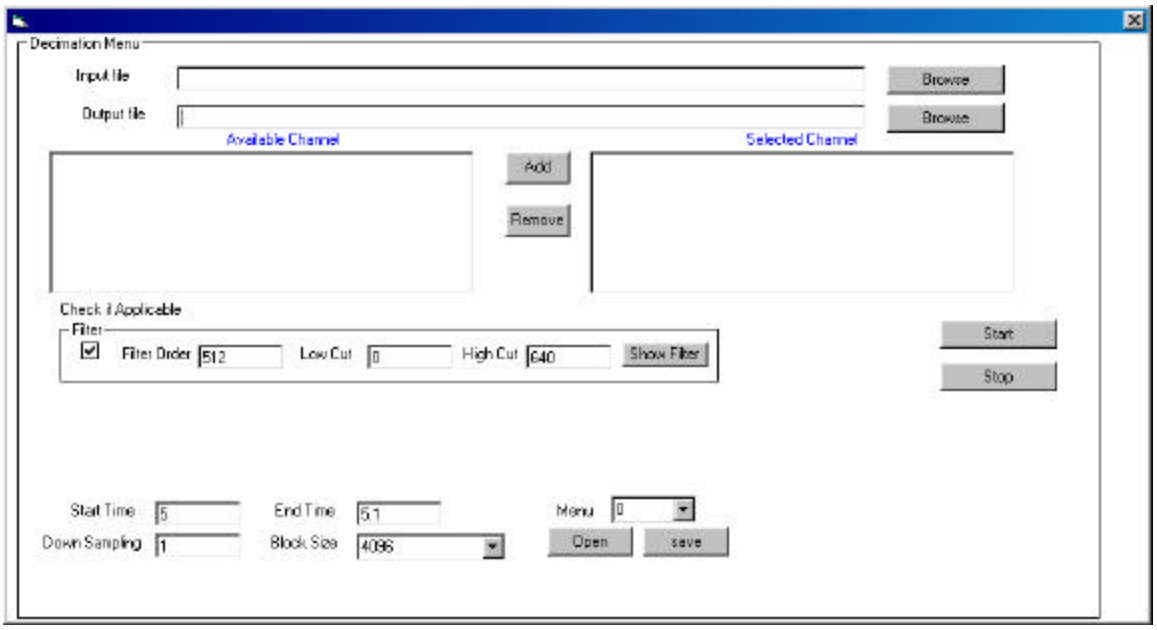


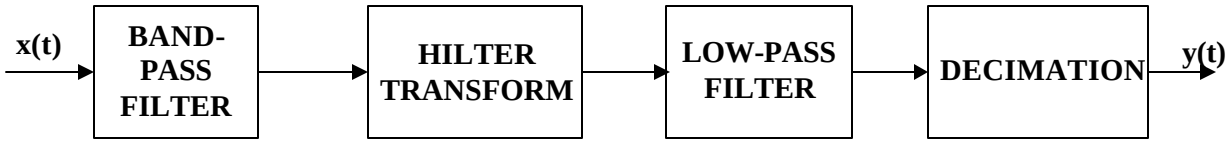
Figure 6.2 - Generate Decimation Data Menu Page

Menu Item	Description of Generate Decimation Data Menu Page
Input File	Name of input file for processing
Output File	Name of output file for processing.
Available Channels	Name of channels available in the input file for processing..
Selected Channels	Channels to be processed for output.
Pre-Decimation Filter	Check box to the left must be selected in order to perform pre-Decimation filtering. User enters appropriate numbers for "Filter Order," "Low Cut," and "High Cut." User can click "Show Filter" to see what a graph of filter in use. Filter parameters can also be set during the process as displayed in figure.
Start Time	Start time to generate decimation data.
End Time	End time to generate decimation data.
Decimation Factor	Decimation number for down sampling (must be an integer number). The new sampling frequency of the output file will be reduced by Decimation Factor.
Block Size	Block size for block processing (also equals to the FFT size used internally for filtering).
Menu	Allows user to open previous settings or save current settings.
Start	Start the decimation process.
Stop	Terminates the decimation process.

Table 6.2 - Description of Generate Decimation Data Menu Page

6.3 Generate Envelope Data

This option allows the users to generate the envelop signal of an input data over any user-selected frequency band using the algorithm shown below. If desired, the resulting envelop signal can also be down-sampled.



Procedure for Generate Envelop Data:

1. Click "Generate Data" Main menu item, and select "Generate Envelop Data," a "Generate Envelop Data" menu page as shown in figure 6-3 will popup.
2. Select input data file to be decimated from "Input File" using "Browse" button. Header information of the selected file can be view from the "Header" button.
3. Select output data file from "output File" using "Browse" button. Header information of the output file will be automatically created which can be view from the "Header" button.
4. Selected channels of input file to be processed in the "available Channels" box by highlighting the desired channels from the input channel list and click "Add." To remove a channel from the output list, highlight and click "Remove." The selected channels will then be shown on the "Chosen Channels" box.
5. Select the Pre-Envelope filter (band pass) characteristics either by directly entering the 3 boxes for "Filter Order," "Low cutoff," and "High cutoff," or from the menu page of "Show Filter." The frequency band selected here will be utilized to compute the envelop signal.
6. Select the Post-Envelope filter (low-pass) characteristics for Decimation.
7. Select the star/end time for envelope analysis from the "Start Time" and "End Time" boxes.
8. Select the block size (e.g. 4096) for filtering processing from the "Block Size" box.
9. Enter the desired down-sampling factor (must be an integer) in the "Decimation factor" box.
10. To save current settings for future use, choose appropriate number from drop-down "Menu" list and click "Save." Selecting a menu number and clicking "Open" will retrieve previously saved filter settings.
11. Click on "Start" to start the envelop process. Click "Stop" to stop the process.

Note: The higher cutoff frequency in post-envelops filter must be smaller than:
(sampling frequency)/(2*decimation factor)

Menu Item	Description of Generate Envelop Data Menu Page
Input File	Name of input file for processing
Output File	Name of output file for processing.
Available Channels	Name of channels available in the input file for processing..
Selected Channels	Channels to be processed for output.
Pre-Envelop Filter	Check box to the left must be selected in order to pre-envelop filtering. User enters appropriate numbers for "Filter Order," "Low Cut," and "High Cut." User can click "Show Filter" to see filter's transfer function. Filter parameters can also be set during the process as displayed in figure.
Post-Envelop Filter	Same as setting pre-envelop filter parameters.
Start Time	Start time to generate envelope data.
End Time	End time to generate envelope data.
Decimation Factor	Decimation number for down sampling (must be an integer number). The new sampling frequency of the output file will be reduced by Decimation Factor.
Decimation	Decimation number while processing data.
Block Size	FFT size.
Menu	Allows user to open previous settings or save current settings.
Start	Start the envelope process.
Stop	Terminates the envelope process.

Table 6.3 - Description of Generate Envelop Data Menu Page

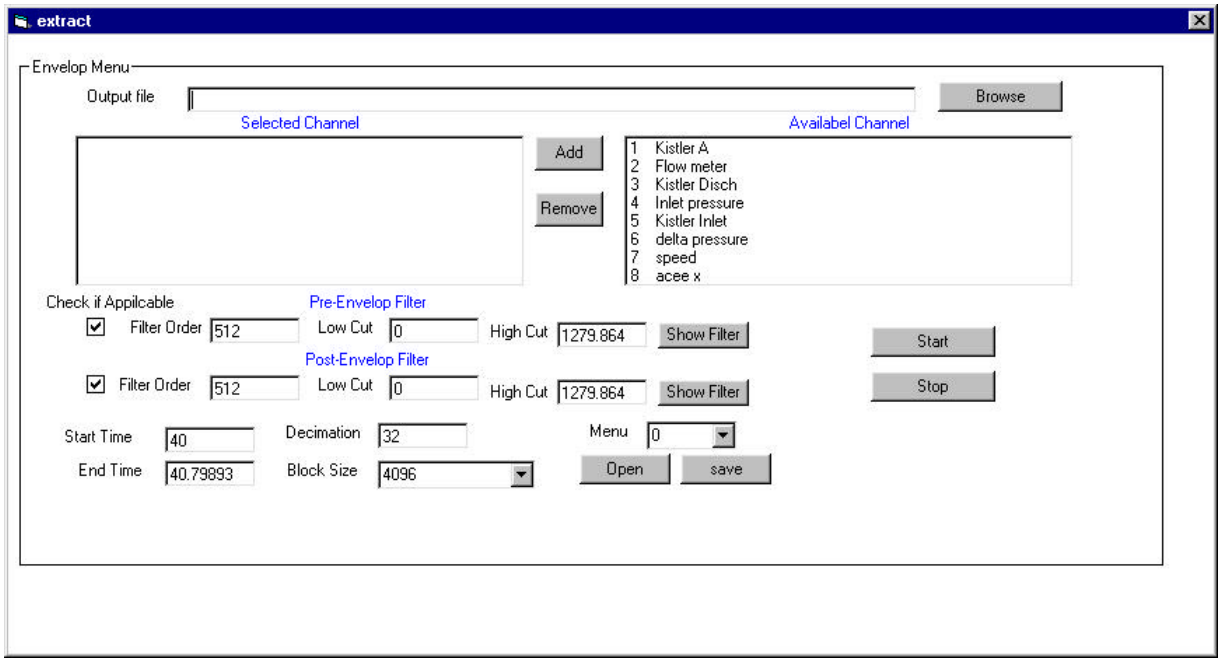


Figure 6.3 - Generate Envelop Data Menu Page

6.4 Generate Order Tracking Data (Advanced Module only)

This option allows the users to generate the Order Tracking (OT) signal of an input data. The Order Tracking (OT) method is based on a referenced key-phasor signal to achieve time domain frequency normalization with respect to RPM so that the number of data point within each revolution will maintain absolute constant.

Procedure for Generate Envelop Data:

1. Click "Generate Data" Main menu item, and select "Generate Order Tracking Data", a "Generate Order Tracking Data" menu page as shown in figure 6-4 will popup.
2. Select input data file from "Input File" using "Browse" button. Header information of the selected file can be view from the "Header" button.
3. Select output data file from "output File" using "Browse" button. Header information of the output file will be automatically created which can be view from the "Header" button.
4. Selected channels of input file to be processed in the "Available Channels" box by highlighting the desired channels from the input channel list and click "Add." To remove a channel from the output list, highlight and click "Remove." The selected channels will then be shown on the "Chosen Channels" box.
5. Select the star/end time for OT analysis from the "Start Time" and "End Time" boxes.
6. Select the block size (e.g. 4096) for filtering processing from the "Block Size" box.
7. To save current settings for future use, choose appropriate number from drop-down "Menu" list and click "Save." Selecting a menu number and clicking "Open" will retrieve previously saved filter settings.
8. Click on "Start" to start the OT processing. Click "Stop" to stop the process.

Menu Item	Description of Generate Order Tracking Data Menu Page
Input File	Name of input file for processing
Output File	Name of output file for processing.
Available Channels	Name of channels available in the input file for processing..
Selected Channels	Channels to be processed for output.
Start Time	Start time to generate envelope data.
End Time	End time to generate envelope data.
Block Size	FFT size.
Menu	Allows user to open previous settings or save current settings.
Start	Start the envelope process.
Stop	Terminates the envelope process.

Menu Item	Order Tracking Signal Menu Item \Description
Original Key	Enter an approximate key-phase frequency (not Sync frequency)

Phasor Frequency	within the processing time frame. For example, if RPM is about 6000 (100 Hz) and the key-phase has 4 pulses/revolution, then key-phase frequency = 4 * 100 = 400 Hz
Original # of points per key phasor period	For information only. User cannot enter in this box. From the original Key Phasor Frequency, the program automatically computes the approximate Number of sampled point between 2 consecutive pulses of key phasor. # of point per key phasor = sampling frequency/key-phasor frequency
New # of point per key phasor period	Specify the desired number of points between 2 consecutive pulses when performing OT resampling. A recommended number is the next larger integer in the "Original # of points per key phasor period" box.
New Key Phasor Frequency	OT provided a frequency normalization effect since the number of data point within each revolution will maintain absolute constant. As a result, its key-phase (RPM) frequency also becomes constant. New Key Phasor Frequency = sampling frequency/ New # of point per key phasor period
Threshold Level	Threshold level applied to the key-phasor pulses for RPM counting
Key Phasor Channel	Select the key-phasor channel

Table 6.4 - Description of Generate Order Tracking Data Menu Page

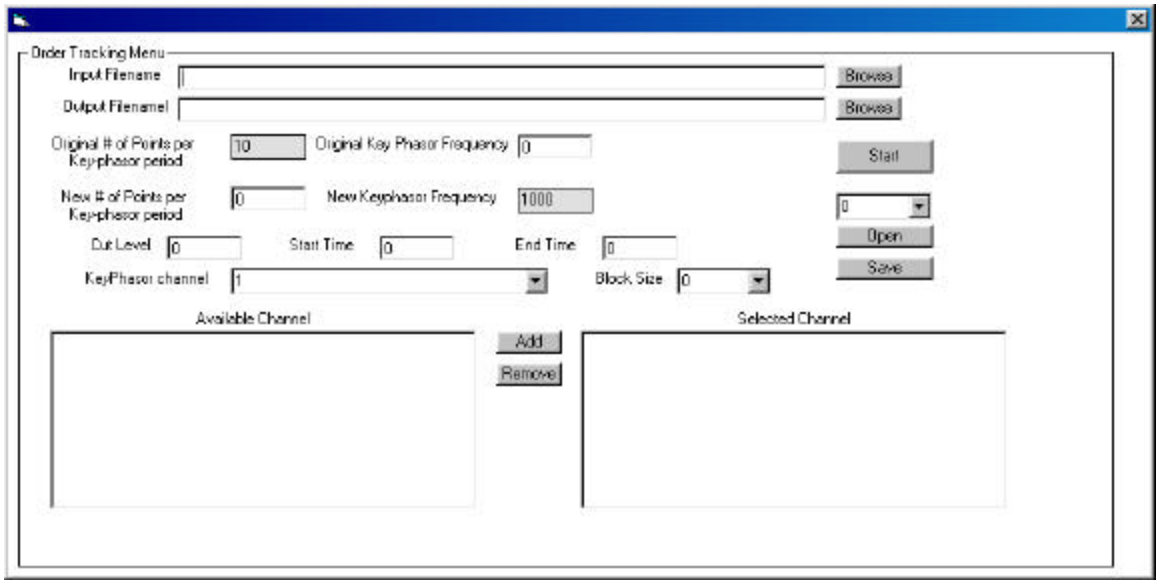


Figure 6.4 - Generate Order Tracking Data Menu Page

6.5 Generate PSEM Data (Advanced Module only)

This option allows the users to generate PSEM signal of an input.

Procedure for Generate PSEM Data:

1. Click "Generate Data" Main menu item, and select "Generate PSEM Data," a "Generate PSEM Data" menu page as shown in figure 6.5 will popup.
2. Select input data file from "Input File" using "Browse" button. Header information of the selected file can be view from the "Header" button.
3. Select output data file from "output File" using "Browse" button. Header information of output file will be automatically created and be viewed from the "Header" button.
4. Selected channels of input file to be processed in the "available Channels" box by highlighting the desired channels from the input channel list and click "Add." To remove a channel from the output list, highlight and click "Remove." The selected channels will then be shown on the "Chosen Channels" box.
5. Select the star/end time for PSEM analysis from the "Start Time" and "End Time" boxes.
6. Select the key-phasor channel in the " Reference Key-Phasor Channel."
7. Click on "Start" to start the PSEM processing. Click "Stop" to stop the process.

Menu Item	Description of Generate PSEM Data Menu Page
Input File	Name of input file for processing
Output File	Name of output file for processing.
Available Channels	Name of channels available in the input file for processing..
Selected Channels	Channels to be processed for output.
Start Time	Start time to generate envelope data.
End Time	End time to generate envelope data.
Reference Channel	The channel for computing the instantaneous phase from a reference spectral component at the user-selected center frequency
Pass Band of band pass filter	The Pass Band of the band pass filter used at the center frequency
Center Frequency	The center frequency of the reference spectral component
Start	Start the envelope process.
Stop	Terminates the envelope process.

Table 6.5 - Description of Generate PSEM Data Menu Page

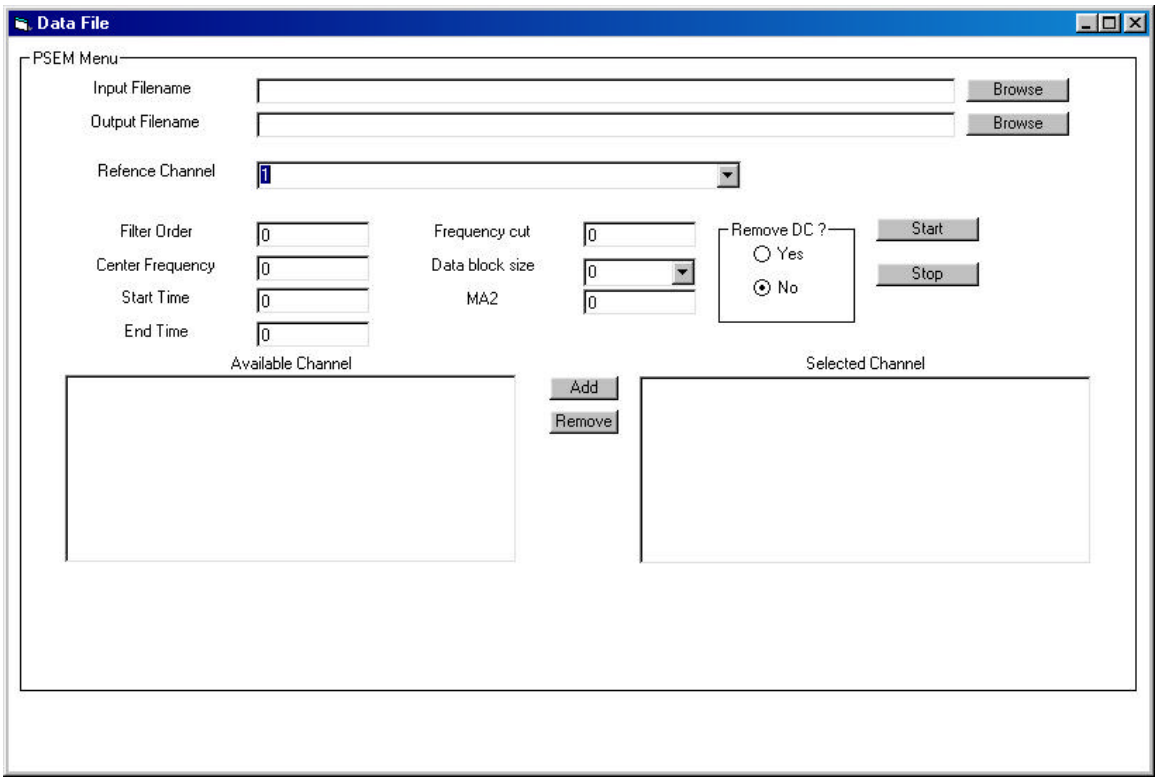


Figure 6.5 - Generate PSEM Data Menu Page

7.0 Utility

"Utility" provide a number of utility tools to extract or merge data from ASCII or binary files, or to convert data file in other format into standard PC-SIGNAL Format.

7.1 Extract/Merge File

This option allows user to extract or merge data from PC-Signal data file(s). User can:

1. Extract a sub-group of channels from *one* data file over a portion of total time period, and generate a new data file for it.
2. Merge a sub-group of channels from *two* data files over a portion of total time period, and generate to a new data file for it.

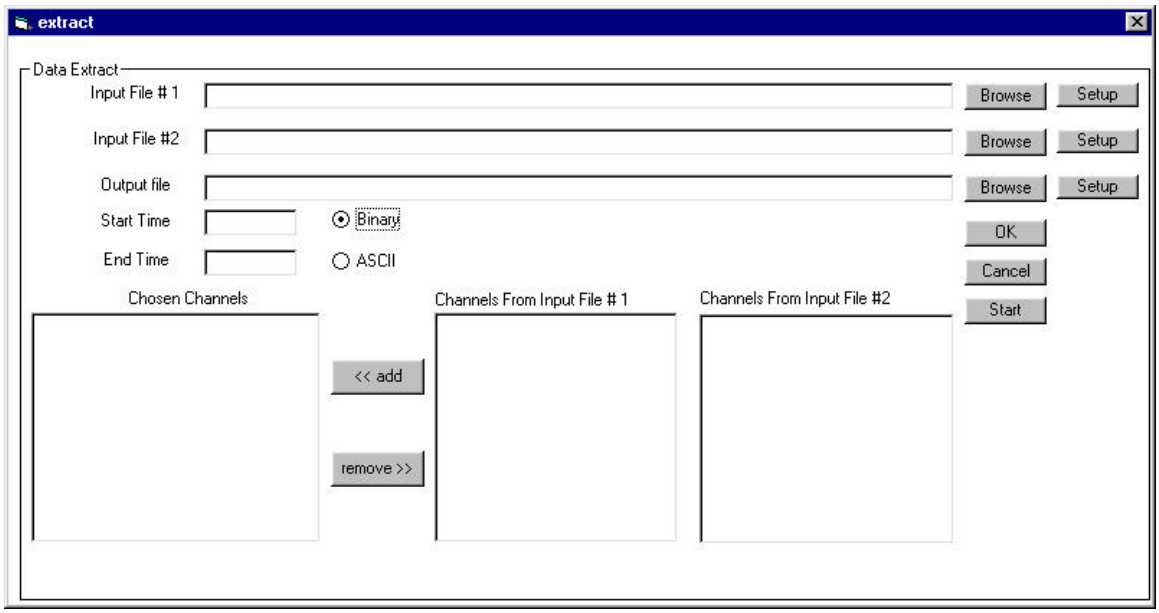


Figure 7.1 - Extract/Merge Menu Page

Parameter Name	Parameter Function
Input File #1	File name of input file #1. It is set by clicking the "Browse" button to the right. Setup can be viewed and edited by clicking the "Setup" button.
Input File #2	File name of input file #2. It is set by clicking "Browse" button on the right. Setup can be viewed and edited by clicking the "Setup" button.
Output File	Output file name. It also set by clicking "Browse."
Start Time	Start time to begin extracting or merging data.
End Time	End time to terminate extracting or merging data.
Binary/ASCII	Output file type.

Table 7.1 - Description Extract/Merge Menu item

Extract File Procedure:

1. Click on "Utility" Main Menu item, and click on the "Extract/Merge" option. An Extract/Merge Menu Page as shown in figure 7.1 will pop up.
2. Check the "Extract from 1 file" option.
3. Select input data file from "Input File" using "Browse" button. Header information of the selected file can be view from the "Header" button.
4. Select output data file from "output File" using "Browse" button. Header information of the output file will be automatically created which can be view from the "Header" button.
5. Select the star/end time from the "Start Time" and "End Time" boxes.
6. Selected channels to be extracted in the "Channels from Input File" box by highlighting the desired channels from the input channel list and click "Add >>" To remove a channel from the output list, highlight and click "Remove." The selected channels will then be shown on the "Chosen Channels" box.
7. Select the desired binary/ASCII option. Binary format data file can be read by PCSIGNAL.
8. Click on "Start" to start the extract process.

Merge Files Procedure:

1. Click on "Utility" Main Menu item, and click on the "Extract/Merge" option to bring up Extract/Merge Menu Page.
2. Check the "Merge 2 files" option.
3. Select input data file #1 from "Input File #1" using "Browse" button.
4. Select input data file #2 from "Input File #2" using "Browse" button.
5. Select output data file from "output File" using "Browse" button. Header information of the output file will be automatically created which can be view from the "Header" button.
6. Select the star/end time from the "Start Time" and "End Time" boxes.
7. Selected channels of input file #1 to be merged in the "Channels from Input File #1" box by clicking on the desired channels and click on "Add >>" button.
8. Selected channels of input file #2 to be merged in the "Channels from Input File #2" box by clicking on the desired channels and click on "Add >>" button. All the selected channels will then be shown on the "Chosen Channels" box.
9. Select the desired binary/ASCII option. Binary format data file can be read by PCSIGNAL.
10. Click "Start" to start the merge process. Click "OK" to exit from this option. An explanation of each parameter is provided in table 7.1.

7.2 Other Data Conversion

This option allows the user to convert data files from PC to UNIX format or vice versa, see figure. Explanations for each parameter are in the following table.

Parameter Name	Parameter Function
Input File	Name of input file. "Browse" button is used to set the file name.
Output File	Name of output file. Click "Browse" to set the name.
Unix to PC/PC to Unix	Original and destination file format to convert data from and to.
Start	Begin data conversion.

Table 7.2 - Data Conversion Window Parameters

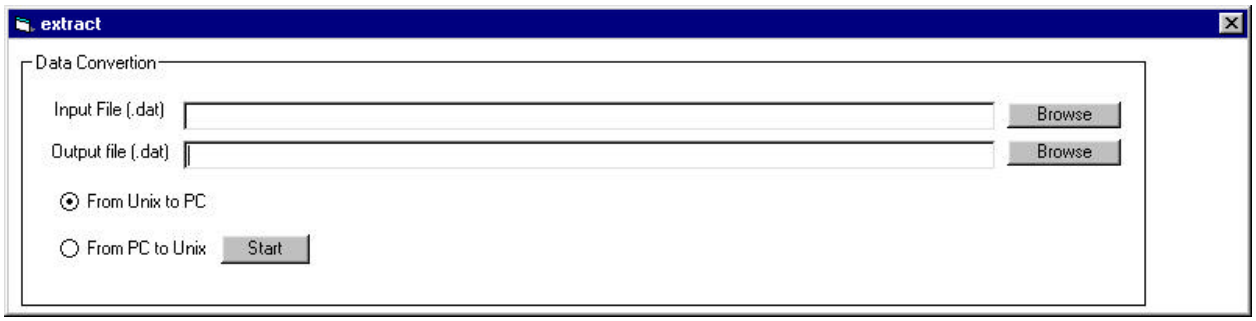


Figure 7.2 - Data Conversion Window

8.0 Page Setup

"Page Setup" allows a user to configure the plot format setup (x/y scale, labels, color etc.) for all sub-plots displayed either on screen or printed out. Even though such plot format setup can also be achieved by setting each individual sub-plot from its M-Menu, but this "Page Setup" provides a more convenient way to so. By clicking "Page Setup" main menu item, a Page Setup menu page as shown in Figure 8.1 will popup. Table 8.1 lists the description of the Page Setup menu items.

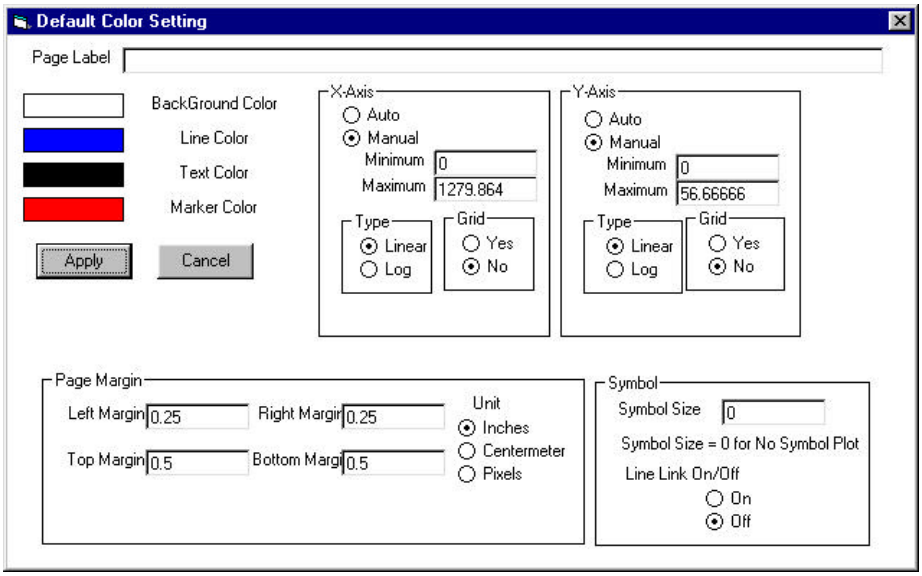


Figure 8.1 - Page Setup Menu Page

Menu Item	**Description of Menu Item in Page Setup Menu Page**
Page Label	This sets page label for each print out.
Color	This sets background, line, and text colors for screen and prints plots. It also sets marker on screen.
Axes setup	Same as X-Axis and Y-Axis setup in "Function Windows."
Page Margin	This sets page margin for print plots.
Symbol Size	This sets symbol styles of plots.
"Apply"	Click "Apply" to update the current page setting.
"Cancel"	Click "Cancel" to discard any modifications.

Table 8.1 - Description of Page Setup Menu Page

9.0 Batch

9.1 "Batch" Menu Page

"Batch" allows user to automate a sequence of processing tasks as a batch job. Figure 9.1 shows the Menu page for setting up the batch processing. Description of the batch menu items is listed below:

Menu Items	Description of Batch Menu Page
(Batch)File Name (optional)	Displays the name of batch file the user is using. Click "Open" to use a saved batch file. Choose "Save" to save current settings into a file.
Files to be processed	Names of files to be used in batch processing. They can be added by clicking "Add" button. Highlight file name and click "Remove" will erase the file from the batch job.
Save Data [Y/N]	Allows user to save processed data into files, with extensions ".basket" and ".draw" for each page. Using Basket function of PC Signal can later retrieve saved data.
No of Pages	Total number of pages of graphs to be processed.
"Update"	To confirm changes to page settings, click "Update."
"Previous Page"	To modify the previous page, click "Previous Page" button.
"Go to Page"	To jump to a particular page, enter the page number to the right of the button "Go to Page" and click it.
"Open Setting."	To retrieve saved settings, click on the appropriate setting number in the drop-down box and then click "Open Setting."
"Save page Setting."	To save current page setting for future use, choose an appropriate setting number and click "Save Setting."
Start Channel/Apply	Using the first page setting, apply to the rest of the pages with identical setting but different channel. The channel starts from the 'Start Channel' setting with increment of 1 until reach the last page.
Preview	Check this box to preview the pages. A dialog box will appear after each page. Only after user click ok will then the next page be processed
Print	Check this box to print.
Save Picture	Check this box to save bitmap files of processed plots.
Save Data	Processed data will be saved into "Basket" files if selected.
Save Database	Processed data will be saved into the database specified in the "Database Name" box.

Table 9.1 - Description of Menu Items in Batch Menu Page

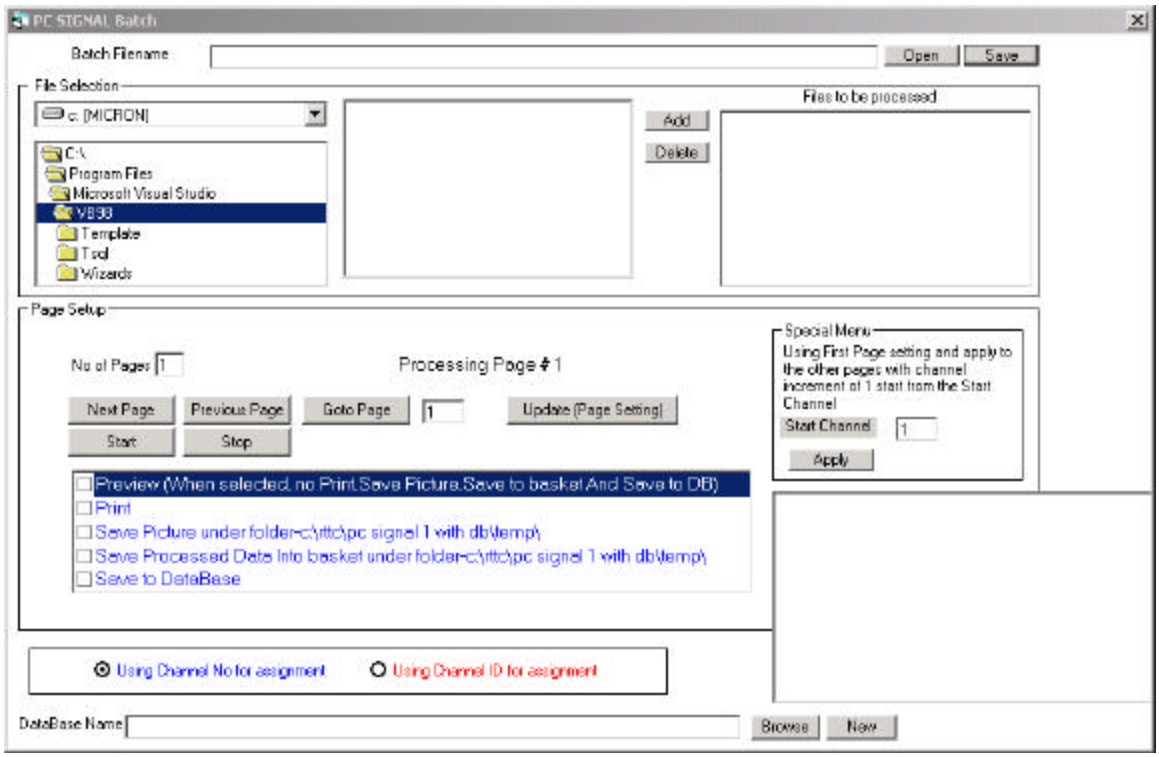


Figure 9.1 - Batch Window

9.2 Batch Processing Procedure

Typical procedure for Batch processing is as follows:

1. Click the "Batch" button, a batch menu page (Figure 9.1) will be shown.
2. Use the "Add" button to select all the data files need to batch-processed. (Use "Delete" button to remove an unwanted data file from the "File to be processed" list.)
3. Specify number of pages to be batch-processed in the "No. Of Pages" box.
4. To set page settings for each page, go to the "Function Window" that pops up. Set up the processing functions as if it were a regular "Function Window." Click "Update" to confirm the changes made in the "Function Window."
5. To set page settings for next page, click "Next Page." Repeat this setup until all batch-processed pages is completed.
6. Check "Print" if want to print all batch-processed pages to printer.
7. Check "Preview" if want to display all batch-processed pages on screen for user preview
8. Check "Save Picture" to save processed data into the bitmap files.
9. Check "Save Data" to save into the "Basket" files.
10. Check "Save to Database" to save into the specified Database Filename.
11. Click "Start" to start the batch processing. Click "Stop" to terminate the process

Section 10 PC-Signal Features Glossary

10.1 Time Domain Waveform Analysis

Histogram: A histogram is a means of displaying the time domain statistics of the waveform. A user can examine a histogram to determine readily whether the waveform is pure noise, or a mixture of sine waves (i.e., periodic signals) and noise and the degree of randomness of the noise. Furthermore, the histogram can be analyzed to obtain specific measures of randomness for a given histogram.

Statistics: The software calculates a number of statistical measures include Mean, RMS, Skewness, Kurtosis, Max/Min, and Crest Factor as defined below. PC-SIGNAL calculates the measure that the user selects from this list and displays how it varies over the time span that the user has selected. By inspecting the resulting data plot, the user can frequently find a relationship between variations in the value of the statistical measure and external events or phenomenon that he is aware of.

Let {x(n); n=0,1,...,N-1} represent an N-point sequence of real numbers. Then the following statistical measures are defined for the sequence.

$$Mean = \bar{x} = \frac{1}{N}\sum_{i=0}^{N-1} x(i) \tag{1.1}$$

$$RMS = \sqrt{\frac{1}{N}\sum_{i=0}^{N-1}[x(i)-\bar{x}]^2} \tag{1.2}$$

$$Skewness = \{\frac{1}{N}\sum_{i=0}^{N-1}[x(i)-\bar{x}]^3\} / RMS^3 \tag{1.3}$$

$$Kurtosis = \{\frac{1}{N}\sum_{i=0}^{N-1}[x(i)-\bar{x}]^4\} / RMS^4 \tag{1.4}$$

$$Max/min = \{ Max\ of\ x(i),\ Min\ of\ x(i) \} \tag{1.5}$$

$$Crest\ Factor = Peak/RMS\ \ where:\ \ Peak = 0.5\ \{ Max\ of\ x(i)\ -Min\ of\ x(i) \} \tag{1.6}$$

Let $\boxed{Mk = 1/N\ \Sigma\ x^k(i)}$ and $\boxed{\mu = M1}$ and $\boxed{Ck = 1/N\ \Sigma\ [\ x(i)-m\ ]^k}$

$C2 = 1/N\ \Sigma\ [\ x(i)-\mu\ ]^2 = 1/N\ \Sigma\ [\ x^2(i)-2\mu x(i) + \mu^2] = M2 - 2\mu * \mu + \mu^2 = \boxed{M2 - \mu^2}$

$C3 = 1/N\ \Sigma\ [\ x(i)-\mu\ ]^3 = 1/N\ \Sigma\ [\ x^3(i)-3\mu x^2(i) +3\mu^2\ x(i) - \mu^3] = M3 - 3\mu\ M2 + 3\mu^3 - \mu^3$

$= \boxed{M3 - 3\mu\ M2 + 2\mu^3}$

$C4 = 1/N\ \Sigma\ [\ x(i)-\mu\ ]^4 = 1/N\ \Sigma\ [\ x^4(i)-4\mu x^3(i) +6\mu^2\ x^2(i) -4\ \mu^3\ x(i) + \mu^4\ ]$

$= M4 - 4\mu\ M3\ + 6\mu^2\ M2 -4\ \mu^3\ \mu + \mu^4\ = \boxed{M4 - 4\mu\ M3\ + 6\mu^2\ M2 -3\ \mu^4}$

$$\boxed{\sigma = RMS = \sqrt{C2}}$$

$$\boxed{s = Skewness = C_3 / \sigma^3}$$

$$\boxed{k = Kurtosis = C_4 / \sigma^4}$$

10.2 Discrete Fourier Transform

The FFT module in PC-SIGNAL produces a Discrete Fourier Transform (DFT) and an Imaginary Discrete Fourier Transform (IDFT) from a time waveform. The DFT and IDFT, N point sequences of complex numbers { x(n); n=0,1,...,N-1}, are defined as:

$$\text{DFT:} \quad X(k) = \frac{1}{N}\sum_{i=0}^{N-1} x(n) W_N^{kn} \qquad \text{k=0,1,….,N-1} \tag{2.1}$$

$$\text{IDFT:} \quad x(n) = \sum_{k=0}^{N-1} X(k) W_N^{-kn} \quad \text{n=0,1,…N-1} \tag{2.2}$$

$$\text{Where:} \quad W_N^{kn} = e^{-j(2\pi/N)}$$

PC-SIGNAL displays the transform results in various ways as described below.

10.3 Linear Spectral Analysis

The mathematical basis for each spectral display uses one or more of the following symbols in its formula. For brevity, symbol is defined here. The symbol $\{x_i(n); n=0,1,N-1; \ i=1,2,...,NB\}$ represents the i-th block of an N-point sequence of real numbers with a sampling frequency, F_S.

And N = Data Block Size (FFT Size)

NB = total # of data blocks for averaging

$\Delta = F_S / N$ = Frequency Resolution

10.3.1 Auto Spectral Analysis

In PC-SIGNAL, Auto Spectral Analysis produces the following display variations of the FFT output.

Power Auto-Spectrum: The software applies the Fast Fourier Transform (FFT) algorithm to process time waveforms to obtain frequency component amplitudes and phases. When spectral analysis is applied to a single measurement, the mean square value at each frequency component is the amplitude of the resulting Power Auto Spectrum. The related mathematical formula is follows.

$$S_{xx}(k) = \frac{1}{NB}\sum_{i=1}^{NB} 2\,|X_i(k)|^2 \ (\mathrm{EU}^2) = \text{Power Auto-Spectrum} \tag{3.1}$$

Power Spectral Density (PSD): The PSD is a power auto-spectrum that is normalized by its frequency resolution Δ.

$$PSD(k) = \frac{1}{NB}\sum_{i=1}^{NB} \frac{2\,|X_i(k)|^2}{\Delta} \ (\mathrm{EU}^2/\mathrm{Hz}) = \text{Power Spectral Density (PSD)} \tag{3.2}$$

The PSD is the basic tool for evaluating dynamic measurements. After inspecting this display, a user will frequently deduce the appropriate inferences to use the information effectively. Also, the display is employed to verify that the raw data meets criteria for validity.

Auto Spectrum: The Auto Spectrum is the square root of power auto spectrum. Its amplitude represents the RMS (Root Mean Square) value of a spectral component.

$$S_x(k) = \sqrt{S_{xx}(k)} = \sqrt{\frac{1}{NB}\sum_{i=1}^{NB} 2\,|X_i(k)|^2} = \sqrt{2} * \sqrt{\frac{1}{NB}\sum_{i=1}^{NB} |X_i(k)|^2} \ (\mathrm{EU}) = \text{auto-spectrum} \tag{3.3}$$

Auto-Correlation: The Auto-Correlation is the average of the product of a signal at time t and its time-delayed counterpart value at t+τ.

$$R_{xx}(\tau) = E[x(t)x(t+\tau)] = FFT^{-1}[S_{xx}(k)] \ (\mathrm{EU}^2) = \text{Auto-Correlation} \tag{3.4}$$

Cepstrum: The Cepstrum is the FFT of the Power Auto-Spectrum.

$$CEPS(q) = FFT[S_{xx}(k)] \ (\mathrm{EU}^2) = \text{Cepstrum} \tag{3.5}$$

The mean square value of a spectral component is computed from the following relationship.

$$\sigma^2 = \frac{1}{N}\sum_{k=0}^{N-1} |x(n)|^2 = \sum_{k=0}^{N-1} |X(k)|^2 = 2\sum_{k=0}^{N/2-1} |X(k)|^2 = \sum_{k=0}^{N/2-1} S_{xx}(k) = \Delta \sum_{k=0}^{N/2-1} PSD(k) \tag{3.6}$$

If the FFT size in generating PAS is NFFT, then the FFT size used for Cepstrum generation will be NFFT/2. The resulting Cepstrum will have NFFT/4 points of data in Quefrency (pseudo time) domain corresponding to 0 to Qmax, where Qmax = 0.5 * Block Time = 0.5 * NFFT/Fs (Fs = sampling frequency). If there exists a sequence of peaks in PSD with frequency

separation of "Fsep" (Hz), it will exhibit a peak in Cepstrum domain at fundamental Quefrency of "1/Fsep".

Spectral Component Tracking: This is a processing technique to track and display the change in frequency and amplitude with time of a spectral component. In rotary equipment, a tracking display is particularly helpful by showing how a frequency component shifts value as shaft speed varies with time.

Spectrogram and Waterfall Display: A 3-dimensional plot displaying the amplitude of spectral components as a function of both time and frequency. The frequency spectrum is displayed as a curve for each specified time interval where the amplitude variations are indicated by different colors. Multiple such curves (for different times) are displayed simultaneously. This display quickly shows the user key aspects of the variations in spectral relationships for both time and frequency. For rotary-machine data, the frequencies that are closely correlated with shaft speed are very easy to see.

Filtering: A processing technique to reduce the range of frequency components to be extracted from a time waveform with the FFT process. Low-pass filtering eliminates all components below the selected value. High-pass filtering eliminates all the components above the selected value. Band-pass filtering combines these two to eliminate components above and below the selected frequency band to be passed through the filter. The user can filter a data set to restrict the processed data to a specific range of interest, or the user can employ the output of a band-pass filter to generate envelope spectra for evaluation.

Frequency Matching: Frequency matching allows a user to evaluate a spectral component by matching its frequency to a list of characteristic frequency values that are stored in a frequency table. In this technique, the user has knowledge of certain frequency values that he desires to find in a given spectral plot. To expedite this process using PC-SIGNAL, the user first inputs a list of the desired frequency values with identification labels through the keyboard. With this list, the user can apply the Frequency Matching algorithm to every spectral analysis result and get a display of the frequencies that are present in the file being analyzed.

10.3.2 Cross Spectral Analysis:

Power Cross Spectrum: In cross spectral analysis, the FFT algorithm is applied to two measurements. The amplitude of Power Cross Spectrum is the product of the component complex (i.e., real and imaginary) amplitudes of the two measurements. A Power Cross Spectrum is employed to evaluate the significance of components that are common (correlated) to both waveforms.

$$S_{xy}(k) = \frac{1}{NB}\sum_{i=1}^{NB} 2X_i^*(k)Y_i(k) \quad (\mathrm{EU}^2)= \text{Power Cross Spectrum} \qquad (3.7)$$

Transfer Function: The Transfer Function is a ratio of two spectral functions, one (the denominator) is on the input of a device or process and the other, the numerator, is the output spectrum. This is also called the "generalized frequency response." It is very useful for assessing the performance or characteristics of a device. Provides clear indication of the part of an output spectrum that is directly related to the input. This display is also called the Frequency Response Function (FRF).

$$H_{xy}(k) = \frac{S_{xy}(k)}{S_{xx(k)}} \text{ (Non-dimension)= Transfer Function or FRF} \quad (3.8)$$

Transmissibility: Transmissibility is simply the inverse of the Transfer Function.

$$TRANS_{xy}(k) = \frac{1}{H_{xy}(k)} \text{ (Non-dimension) = Transmissibility} \quad (3.9)$$

Linear Cross Coherence: Linear Cross Coherence, a normalized cross spectrum, measures the degree of linear dependence between the two input measurements and is displayed as a function of frequency. This is another analysis tool that a user can apply to determine the valid range of the available data. On display plots, this relationship is frequently labeled COH.

$$COH_{xy}(k) = \left| \frac{S_{xy}(k)S^{*}_{xy}(k)}{S_{xx}(k)S_{yy}(k)} \right| \text{ (non-dim)= Linear Cross Coherence} \quad (3.10)$$

Impulsive Response Function (IRF): The IRF is the inverse Fourier Transform of the Transfer Function.

$$h_{xy}(t) = FFT^{-1}[H_{xy}(k)] \text{ (Non-dimension)= Impulsive Response Function (IRF)} \quad (3.11)$$

Cross Correlation: The Cross Correlation is the average of the product of a signal x(t) at time t and another signal y(t) at time-delayed t+τ.

$$R_{xy}(\tau) = E[x(t)y(t+\tau)] = FFT^{-1}[S_{xy}(k)] \text{ } (EU^2) \text{ = Cross Correlation} \quad (3.12)$$

Phase Tracking: A processing technique to track and display the Transfer Function phase changes of a selected frequency component whose frequency may be drifting. This technique is very effective for analyzing data from rotary machines where the components are related to the shaft speed. The user sets up this process to display how the phase of a selected spectral component shifts value as the machine speeds up or slows down. Usually, the phase is between a vibration measurement and a speed measurement.

10.4 Shock Response Spectrum

A Shock Response Spectrum (SRS) is the response of a structure or mechanical system to the application of a very short transient force. The SRS is an algorithm that calculates the relative significance of all the frequency components that are associated with the shock. The SRS is further defined as the spectral distribution of the maximum relative displacement responses of a

series of single-degree-of-freedom systems. This process is preset to calculate and display the equivalent acceleration responses of the single-degree-of-freedom systems. Because of its very specific characteristics, a user will find a Shock Response Spectrum to be useful in comparing the behavior of a system to two or more transient inputs.

The mathematical formulation is based on the equation of motion for system with a single degree of freedom.

$$m\frac{d^2z}{dt^2}+c\frac{z}{dt}+kz=-m\frac{d^2x}{dt^2} \tag{4.1}$$

$\ddot{x}(t)$ = Input acceleration time history

$y(t)$ = Absolute displacement of m

$z(t)$ = Relative displacement of m to base motion

The following absolute acceleration of m is obtained.

$$\ddot{y}(t)=2\xi\omega_n\int_0^t\ddot{x}(t)e^{\xi\omega_n(t-\tau)}\cos\omega_d(t-\tau)d\tau+(2\xi^2-1)\omega_n^2z(t) \tag{4.2}$$

where: $$z(t)=-\frac{1}{\omega_d}\int_0^t\ddot{x}(\tau)e^{\xi\omega_n(t-\tau)}\sin\omega_d(t-\tau)d\tau \tag{4.3}$$

Damping ratio $\xi=\frac{c}{2\sqrt{km}}=\frac{c}{c_c}$

Natural frequency $\omega_n=\sqrt{\frac{k}{m}}$

The SRS is calculated by determining the maximum value of $\ddot{y}(t)$ for all time. The peak values found during the transient is called the Primary Spectrum, and the peak values found after the transient is called the Residual Spectrum.

10.5 Use of a Window Function for Spectral Analysis to Minimize Leakage

An error is introduced into FFT processing that appears to leak energy from one frequency into adjacent frequencies. The error occurs when a sampled waveform does not contain an integral number of cycles over the time period during which it is analyzed. Windowing is practiced to reduce leakage by multiplying the time waveform by a Window Function to reduce discontinuities at the ends of the waveform. Effective choice of analysis time duration and window function by a knowledgeable user can eliminate this error. PC-SIGNAL provides the following Window Functions for spectral analysis.

1. Rectangular: $w(t) = 1$ for $0 < t < T$
2. Hanning: $w(t) = 1 - \cos(2\pi t / T)$ for $0 < t < T$
3. Hamming: $w(t) = 1.08 - 0.92\cos(2\pi t / T)$ for $0 < t < T$
4. Kaiser_Bessel:
$$w(t) = 1 - 1.24\cos(2\pi t / T) + 0.244\cos(4\pi t / T) - 0.0035\cos(6\pi t / T)$$ for $0 < t < T$
5. Flat Top:
$$w(t) = 0.2810639 - 0.5208972\cos(2\pi t / T) + 0.1980399\cos(4\pi t / T)$$ for $0 < t < T$

When a Window Function is applied, an amplitude correction factor as shown in Table 10.1 must be used so that the composite RMS amplitude will maintain the same value.

When x(t) is the raw data, and y(t) = w(t) x(t) is a windowed version of x(t). Then,

$$S_{yy}(f) = S_{xx}(f) \int |W(\upsilon)|^2 \, d\upsilon = S_{xx}(f) * COR$$

$$Where: \quad COR = \int |W(\upsilon)|^2 \, d\upsilon = \text{Mean Square of w(t)}$$

To maintain the correct overall RMS value (for both discrete or wide band spectra), the correction factor for adjusting the PSD amplitude is:

=> Sxx(f) = Syy(f)/COR

Table 10.1 Window Correction Factors

Window Type	Effective Duration	COR= (1/N) Σ w^2(i)	Noise Bandwidth Δf
Rectangular:	T	1.000	1.000 Δf
Hanning:	0.375 T	1.500	1.500 Δf
Hamming:		1.589	1.589 Δf
Kaiser_Bessel:	0.291 T	1.798	1.798 Δf
Flat Top:		0.234	3.770 Δf

10.6 Raw Data Utilities

PC-SIGNAL includes a group of functions that provides a user significant capabilities to work with raw data files. These utility functions allow a user to convert, decimate, extract, and merge raw data files. The specific application of each process is as follows.

Convert changes the format of the file from its current format to another selected format. For example, from binary to octal.

Decimate reduces the number of samples in a data file by deleting every nth sample. For example, by decimating a file by 2, every second sample is deleted; thus a 100,000-sample file is reduced to a 50,000-sample file.

Extract withdraws a selected subset of samples from file for use. For example, the utility extracts all the samples from a file between the 10^{th} and 20^{th} seconds.

Merge takes two files and interleaves the samples, thus producing a new file with all the samples from the other two.